REMOTE SENSING APPLICATIONS IN FORESTRY

THE EVALUATION OF RANGELAND RESOURCES BY MEANS OF MULTISPECTRAL IMAGERY

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Annual Progress Report — 30 September, 1967

A report of research performed under the auspices of the
FORESTRY REMOTE SENSING LABORATORY,
BERKELEY, CALIFORNIA—
A Coordination Facility Administered Jointly By
The Pacific Southwest Forest and Range Experiment Station of the Forest Service, U.S. Department of Agriculture and by the School of Forestry, University of California

For

NATURAL RESOURCES PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

This study has sought to determine the usefulness of various kinds of photography and other imagery for improving inventories of rangeland resources. Among the kinds of imagery studied were multispectral photography, 18-channel line-scan imagery, thermal infrared and K-band radar imagery and Gemini color photography of various range environments in California and Arizona. The results of remote sensing research conducted on an annual grassland range, a perennial bunchgrass range, and in mountain meadows are discussed in terms of both present applications (using fixed wing aircraft) and potential applications, employing earth orbiting satellites. Included in this annual report is a progress report on rangeland resource interpretations made from Gemini color photography. The limitations, advantages, and potential applications of such photography are discussed and recommended image quality specifications are given for an optimum orbital system for the inventory of range resources. Examples of color composites made by image enhancement techniques are shown and their advantages for increasing the interpretability of imagery are discussed. Factors which may limit the efficient utilization of satellite imagery are pointed out and recommendations for further research to help solve such problems are outlined.

ACKNOWLEDGMENTS

This research was performed under the sponsorship and financial assistance of the National Aeronautics and Space Administration for the Manned Earth Orbital Experiment Program in Agriculture/Forestry (Contract number R-09-038-003--Earth Resources Program).

Presentation of the material contained in this report has been made possible through the cooperative effort of several individuals and organizations. Among the personnel of the Remote Sensing Laboratory, University of California, who contributed to the collection of ground truth, compilation and interpretation of the imagery used in this report were Jerry D. Lent, Eric B. Janes and John Thomas.

Grateful acknowledgment also is given to Dr. Charles E. Poulton, Professor of Range Ecology, Oregon State University, and Edwin H. Roberts, Remote Sensing Laboratory, University of California, for contributing material to Section Two and Six.

Special acknowledgment is given to Dr. Robert N. Colwell for providing supervision for this research project and for editing the final draft.

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SECTION ONE

Introduction

The material contained in this annual report, covering the period June, 1966 to September, 1967, builds upon research performed during the previous year. The research seeks to determine the feasibility of applying remote sensing techniques to the inventory and analysis of rangeland resources. This NASA/USDA sponsored research is but a part of an expanded program that is investigating various Agriculture/Forestry applications of remote sensing consistent with NASA's Earth Resources Program.

During the first year of the study, the project objective was to determine the ease and accuracy of identifying and mapping rangeland resources by means of multispectral imagery obtained by fixed wing aircraft. Various kinds of photography, (Panchromatic, black-and-white infrared, Ektachrome, Ektachrome Infrared) as well as other kinds of imagery (thermal infrared, Radar) of rangeland test sites in California were obtained from the following sources:

NASA's Houston-based Photographic Unit
Cartwright Aerial Surveys, Sacramento, Calif.
C.R.E.S., University of Kansas, Lawrence, Kansas
Barnes Engineering Co., Stamford, Conn.

Preliminary results from the first year of study were reported in "The Use of High Altitude, Color and Spectrozonal Imagery for the Inventory of Wildland Resources", Volume II: The Range Resource. (September, 1966). Briefly summarized they are:

(1) of the conventional aerial photography examined, the most useful single type for differentiating the greatest number of

vegetation and soil types was Ektachrome Infrared. This conclusion is based upon (a) the particular characteristics of the vegetation on the test sites examined; (Ektachrome Infrared has limited use in certain vegetation types), (b) the color rendition which separates objects which are not readily separated on conventional color film, and (c) the relatively sharper image obtained when hazy conditions exist.

(2) Thermal infrared imagery is useful for evaluating important moisture relationships

(3) K-band radar imagery is useful for mapping gross vegetation boundaries. This sensor may be especially useful for obtaining a broad picture of landforms and associated vegetation types in those areas which are difficult to photograph due to persistent cloud cover.

(4) Image enhancement techniques provide a useful means for increasing the interpretability of black-and-white images derived from two or more bands of the spectrum. In fact, color composites made from Panchromatic and black-and-white infrared photos are more interpretable in some respects than either Ektachrome or Ektachrome Infrared photographs. For this reason there are decided advantages to putting a multispectral camera system into earth orbit to obtain multiband black-and-white images, in contrast to camera systems which would obtain color photographs.

(5) Three obvious factors must be considered when attempting to optimize information about wildland vegetation extracted from remote sensing imagery: (1) the time of day or night, and the time

of the year, (2) the scale or resolution obtained by the camera or sensor system, and (3) selection of the appropriate sensor system.

Program Objectives

The objectives of the research performed during the past year and discussed in this report are:

(1) to define range resources and develop a valid picture of the importance of these resources as they relate to the usefulness of space vehicles for solving food problems facing much of the world.

(2) to present, with the use of illustrations from research conducted at various test sites, examples of the capabilities of various kinds of photography and other imagery obtained from various kinds of sensor systems.

(3) to identify resource management problems which could be solved using remote sensing techniques.

(4) to discuss the potential capabilities and alternative requirements of sensors, operating at orbital altitudes, that could provide needed information for the development and management of range resources.

In order to achieve these objectives the following steps were taken:

(1) Test sites of rangeland were established which would provide an opportunity to examine various kinds and conditions of range vegetation.

(2) Samples of the vegetation and soils found in these test sites were taken to the G-E Spectrophotometer in Richmond, Calif. where reflectance curves were made in the .4-1.0 micron wavelength

band. Absolute temperature measurements were made to correlate with tones on thermal infrared imagery.

(3) Various kinds of photography and related imagery were obtained of the vegetation, soil and moisture conditions at each test site. Some of the sensors tested include: Zeiss 6 inch camera, multilens camera, Barnes Engineering camera, thermal infrared imager, and optical mechanical scanner.

(4) Intensive ground-truth observations and measurements were made following procurement of imagery in order to correlate colors and tones, and resolution of significant objects on the imagery with the corresponding phenomena on the ground.

(5) A literature review of range problems and the possible application of remote sensing techniques to these problems was made. Furthermore, conferences with professional people working in range resource management added measureably to identifying range problems and putting them into proper perspective.

Basic Considerations

(extracted from Colwell, R.N. 1966. Uses and Limitations of Multispectral Remote Sensing. Proceedings 4th Symposium on Remote Sensing of Environment, April 12-14, 1966. Univ. of Mich. pp. 71-100)

Whenever the applications of remote sensing techniques are discussed it is appropriate (for the benefit of readers less familiar with remote sensing) to review briefly many of the basic matter and energy relationships that are involved in the remote sensing process. The following points should be emphasized:

(1) In order for a remote sensing system to operate effectively within any specified wavelength range of the electromagnetic spectrum there must be: (a) an energy source, which radiates energy of the proper wavelength; (b) a collection of matter, (i.e. a target) which will interact with this energy; (c) an energy detector, which is sensitive to wavelengths of energy in specific bands of the e-m spectrum (e.g. camera and film, optical mechanical scanner, thermal infrared sensors); (d) a propagating medium between detector and target through which the energy is transmitted; and (e) an energy filter which will screen out undesirable wavelengths of energy, while permitting the desired wavelengths to pass through to the detector.

(2) The radiant power peak of the sun is at a wavelength of about 0.5 microns. It is an ideal energy source for procuring imagery of the earth by use of reflected energy in the visible part of the spectrum, i.e. .4 to .7 microns, as when using panchromatic or color films, or in the near infrared band, i.e. 0.75-1.2 microns, as when using infrared sensitive film. Shorter wavelengths of reflected sun energy, e.g. 0.3-0.4 microns, may be recorded on ultraviolet sensitive film, except when atmospheric haze precludes formation of a useable image.

(3) The radiant power peak of the earth is at a wavelength of about 9.6 microns. Therefore, it is an ideal energy source for procuring imagery of the earth's surface by use of emitted energy in the Thermal infrared band of the spectrum, i.e. 8.0-13.0 micron range.

(4) There are practical methods of obtaining electromagnetic radiation of almost any desired wavelength for use in active remote reconnaissance systems. An active system is one which generates its own energy source. Radar sensors are examples of active systems. They generate long wavelength energy from specialized tubes, circuits and resonating cavity sources. This energy is transmitted to the earth's surface and the returning energy is transformed into a photo-like image which is indicative of the interaction of energy in longer wavelength bands (e.g. 1-3 centimeters). Examples of other sources of energy include: cathode tubes, oscillating dipole sources, masers, lasers, filaments and gas lamps. Because energy is generated independent of the sun's energy it is possible to obtain imagery day or night.

(5) The atmosphere is a turbid medium containing aerosol particles which have diameters commensurate with the wavelength of visible light. Light scattering by most of these particles is inversely proportional to the fourth power of the wavelength of the light, in accordance with Rayleigh's Law.

(6) The atmosphere contains other elements, e.g. N_2, O_2, O_3, H_2O, CO, and CO_2 which attenuate the transmission of wavelengths in specific bands of the electromagnetic spectrum. The location and intensity of each of these bands, called molecular absorption bands, are predictable from a knowledge of the matter and energy relationships for each type of molecule present in the atmosphere.

(7) In attempting to select the combination of filter and sensor which will "optimize" the image quality obtainable by remote reconnaissance, we must recognize that there may be significant variability in: (a) the intensity and spectral composition of the illuminant; (b) the reflectivity and emissivity of the target; (c) the sensitivity of the film or other sensor; (d) the transmissivity of the atmosphere, water or other medium; and (e) the transmissivity of the filter.

Those interested in a more comprehensive treatment of "basic matter and energy relationships" are encouraged to read "Basic Matter and Energy Relationships Involved in Remote Reconnaissance", Colwell, R. N., et al., 1963, Photogrammetric Engineering 29(5): 761-799.

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(b) The [illegible]

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SECTION TWO

Range Resources in Perspective

by

David M. Carneggie
Charles E. Poulton

Introduction

Range, forestry and agricultural cropping make up the three major uses of the land mass of the world. This trinity of land uses feeds, clothes and provides the fiber and shelter for mankind the world over. The extent to which a reservoir of knowledge is developed, integrated and applied among these three land uses largely determines the standard of living, health and welfare of human society. It is upon this trinity of vegetation resources, coupled with the mineral, water and human resources that the economy of any country is built.

In the world picture, range or native pasture provides a major part of the forage production used by livestock and wildlife, and hence is recognized as a major vegetation resource by NASA's Earth Resources Program (National Aeronautics and Space Administration, April, 1967. A Survey of Space Applications ". . . for the benefit of all mankind"). It is our purpose, therefore, to clearly identify and place into perspective the substantial area of the earth's land mass that may be referred to as "range" and the "range resources" derived from this land. It is our hope that this will provide sufficient background for those less familiar with natural resources to see "range" in an improved perspective.

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Earth Resources Program (National [illegible]

tion, April, 1981. A Survey [illegible]

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resources [illegible] from this land. [illegible]

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Range and the Role of the Range Manager

Range refers to all the non-arable land (wildland) that produces or is capable of producing native forage and/or browse for consumption by grazing animals, both domestic and wild. Thus, range includes the concept of habitat for wildlife as well as for domestic animals. Areas of range that are culturally revegetated with introduced forages, where the intent is to achieve a permanent cover by managing the area as though it were a natural ecosystem, are also encompassed by this concept of "range". The term is synonymous with "native pasture", but this does not change its basic identity, merely because of rehabilitation practices,when the primary mode of harvest is by the grazing animal.

Land supporting either commercial or non-commercial overstories of trees and scrub may also have forage or browse in the understory. Consequently, the use of such land for grazing may represent only one of a number of uses within the "multiple-use" concept of land management. In fact, forestry and range uses may be either dominant or subordinate, one to the other, depending upon the ecological characteristics of specific parcels of land.

Range, as defined, may be found in all environments from the tundra to the tropics; but it predominates in the non-forested tundra, steppe, prairie, savanna and semi-arid regions of the world. Throughout this area and most important to the range manager is the vast annually renewable storehouse of cellulose (forage and browse) that is converted into economic goods by the grazing animal. But across this spectrum of environments, range managers and other

scientists are interested in a broad array of products (range resources) in addition to the vegetation around which their interest seems to be centered. Man harvests these goods in the form of livestock and wildlife and their respective animal products (meat, hides, milk, wool, furs) including trophies and intangible recreational values.

While the vegetation and the grazing animals are his primary interest, the role of the range manager and scientist, as a conservationist, is much broader in scope. His concern also includes timber values on grazeable forest areas, interrelationships with cropland agriculture and the impact of range manegement decisions on urban and related industrial problems. The range manager is also aware and concerned about the soils of range areas, annual variation in climate, minerals, water and water yield, fisheries resources, small mammals, birds, insects and disease organisms. All of these factors in the ecosystem interact to: (1) affect the flow of products from the range, or (2) determine other potential land uses and values. In the implementation of his management program, the range manager's ever present objectives are to balance and integrate the various competing and complimentary land uses and to maximize production in keeping with the ecological characteristics of each parcel under his control.

Distribution and Importance of Range Resources

The world distribution of natural vegetation areas that produce forage and browse for grazing animals is shown in Figure 2.1. This reflects the proportion of the Earth's surface that could be brought

under more intensive management for increased food production from range resources. While about 7 percent of the world's land area is in cultivated agriculture (Bruin, Agr. Res. Inst., 1966. p.202), the total area suited primarily for range production comprises nearly one-half of the Earth's land mass.

Drawing upon work by Shantz (1954), Table I provides a more detailed picture of renewable vegetation resources. This table presents the broad geographic types of vegetation within the categories of forests, grasslands, and deserts. These figures emphasize the world-wide importance of each kind of land, but do not recognize the extensive area within forests and deserts which is suited for grazing. Within his paper, however, Shantz acknowledges the grazing potential of forest and desert land, and concludes that 46% of the earth's land surface is potentially grazeable.

Desirable as it would be to present reliable statistics on animal use of range lands, this is impossible. Some estimates of domestic animal numbers and the percentage of range use have been made on a world basis. These do enhance the perspective of range resources. Byerly (1966, Agr. Res. Inst., p. 35), estimates that there are " . . .about 1 billion cattle, 1 billion sheep, 350 million goats, 100 million buffaloes, 11 million camels, 550 million pigs, 64 million horses, 15 million mules, and more than 40 million asses in the world". Peterson (1966) estimates that "...in a great many of the lesser developed countries 80 to 100 percent of the livestock sustenance is derived directly from grazing, the great bulk of which comes from native grasslands". Taking the United States as

an example of a developed country with substantial acreages of steppe, savanna and forest ranges (range and pastureland occupy nearly 1 billion acres), Sprague (1959, ASRM Meeting, Tulsa) considers that cattle obtain more than half of their fodder from ranges and pasture. It has been estimated for the United States that 60 percent of the beef cattle spend significant proportions of their life growing, developing and/or fattening on rangeland. Unfortunately, statistics on herbivorous wildlife use ~~is~~ are even more inadequate. Suffice it to say that, except for somewhat limited use of agricultural crop areas, these wild herbivores derive the majority of their forage and browse from range resource areas.

Theeconomic importance of range resource areas and the animals which they support ~~are~~ is emphasized if we consider the world distribution of livestock industries that are primarily dependent upon the range and pasture areas of the world. The Times Atlas (1958) shows a world map of livestock raising areas that practically overlays the cross-hatched areas in Figure 2.1. If one compares the world distribution maps of cattle, sheep and goat numbers (Guidry, 1964) with Figure 2.1, there is a very high correspondence between the concentration of animal numbers and the natural vegetation types of highest value for forage and browse production. The same is true where similar and more detailed information is available by continents (Konnerup, Agr. Res. Inst., 1966). Thus the important correlation between range resources and the red meat industries of the world should be self-evident.

To complete the picture, it must be pointed out that these same range resource areas plus many millions of acres of forest, tundra

Figure 2.1 Crosshatching represents the areas of natural vegetation which are currently utilized or are potentially suited for production of native forage or improved pasture for grazing animals. (The Times Atlas, 1958)

AREAS OF MAJOR VEGETATION TYPES
THROUGHOUT THE WORLD

	Area in Sq. Miles	Percent of Total Land Area
Forests		
Tropical rain forest	3,800,000	7.5
Temperate rain forest	550,000	0.9
Deciduous forest	6,500,000	12
Coniferous forest	7,600,000	15
Monsoon (dry) forest	2,000,000	3.8
Thorn forest	340,000	0.6
Broad sclerophyll forest	1,180,000	2.1
Total forest	21,970,000	42
Grasslands		
High grass savanna	2,800,000	5.3
Tall grass savanna	3,900,000	7.5
Tall grass	1,580,000	3.1
Short grass	1,200,000	2.4
Desert grass savanna	2,300,000	4.3
Mountain Grassland	790,000	1.4
Total grassland	12,570,000	24
Deserts		
Desert shrub and grass	10,600,000	21
Salt desert	30,000	--
Hot and dry deserts	2,400,000	4.7
Cold desert (tundra)	4,400,000	8.3
Total desert	17,430,000	34

Table 1. The data presented above is from "The place of grasslands in the Earth's cover of vegetation", Shantz, H. L., 1954. Notice that his data indicate "grasslands" occupy only 24% of the total land area of the Earth. However, in his paper Shantz recognizes that there is considerable grazing land within "Forests" and "Deserts"; and concludes that 46% is a more realistic estimate of the potentially grazeable land on the earth's land surface.

and desert are also the home and food source for countless millions of game animals. If placed under management and harvested for maximum herd productivity, these wild animals provide a source of food, clothing and other animal products of extreme importance to man. This is particularly significant in light of attention already being given to the feasibility of planned and carefully managed "...game animal cropping..." in Africa (Konnerup, Agr. Res. Inst., 1966, p. 140).

In all programs involving the harvest of animals--domestic and wild--from range areas, it is of utmost importance to realize that the animal products represent converted "range resources" and that the continued flow of products from these areas is determined by how effectively the range resource is understood and managed.

Ranges represent the world's greatest reservoir of cellulose and fiber, which can be converted to animal protein for human consumption. On most of this land, the only economic way to convert the roughages to useful products is by the grazing animal. These roughages are used in various combinations by domestic, semi-domestic and wild grazing animals, depending on the ecological conditions, nature of the forage resource, and on the socio-economic and religious structure of human institutions in each region. However, man and his animals are not always well adjusted to their environment. Wahlen (1962) has pointed out that, "Unfortunately some of the highest population densities of the world have the lowest animal protein intake, because their high livestock densities are under the worst management". Peterson (1966) says that in many of the lesser developed countries the total production of livestock and the value of the herds

may be considerably below the level of potential productivity as a result of (1) inadequate quantity and/or quality of feed resulting from misuse or mismanagement of the forage resource, and (2) inferior or inefficient grazing animals for converting the roughage to useful protein products.

Some have tried to minimize the importance of animal protein in the future food supply of the world (Bruins, Agr. Res. Inst., 1966). While, as Byerly (Agr. Res. Inst., 1966, p.43) points out, it is technologically feasible to prepare and use meat substitutes, the grazing animal is the most immediate, feasible and economic way to increase protein for human use in developing countries that lack capital and technical capability for expensive agricultural and industrial developments. Cox (Agr. Res. Inst., 1966, p. 184) recognized the importance of range resources and had the following to say about the possibilities of animal production from ranges in Latin America:

> "Livestock will surely play a large role in this expansion if for no other reason than that grazing is a kind of activity that can be carried on with the least amount of land preparation and investment. Livestock raising will probably develop first--prior to the infrastructure required for more intensive land utilization".

Cox further observes that "...the real need is for more production per animal and more production per acre" (p. 185). In addition, Wahlen (1952) in making a case for increasing the animal protein intake of 993 million people who receive less than 10 grams of protein each day, concludes that we need "better bred, better fed, and better managed animals". This is another way of saying that we must increase the awareness of the importance of RANGE RESOURCES and for the applica-

tion of good range management and animal husbandry principles. The starting point is with improved inventories and resource analyses in all of the major range resource areas of the world. Most of the critical problems in range resource management, husbandry of grazing animals and human food production occur in areas where least is known about the native grazing land and its capacity to produce under more modern concepts of range and agricultural management and especially under a program that effectively integrates the trinity of land uses--range, agriculture and forestry--in achieving an optimum contribution to the local economy.

Place of Remote Sensing in Range Management

Consideration of resource management problems brings to light the gross inadequacy of both national and worldwide data on range inventory and resource analysis. What is needed is better information on (1) acreages of useable grazing land by ecologically appropriate classes, (2) the ecological characteristics of each kind of range (phytosociology, plant succession, present range condition, climate, vegetation-soil inter-relationships, and the autecology of the important species), (3) the special management problems associated with different ranges and (4) indices of potential productivity of each kind of range. We also need better information on the numbers and kinds of animals, including wild herbivores, that make use of range resources in contrast to improved farm pasture and temporary leys. Better information is also needed on season and duration of use. This kind of information is necessary both to set land use and development policy and in the management decision process regardless of the intensi-

ty of management that may now prevail. Without this kind of vital information, it is impossible to develop the most sound and efficient management programs--programs aimed at increasing yields of human food to an ecological and cultural maximum. In meeting each of these needs, remote sensing has a place and a substantial contribution to make.

In the interest of solving resource management problems and consistent with NASA's Earth Resources Program, the feasibility of improving range resource inventories and analyses by implementing remote sensing techniques is being investigated. It is visualized that immediate benefits will include: (1) improved inventories and analyses of range and related resources, (2) more accurate land use maps for policy making and planning at national levels in the development of a country's natural resources, (3) increased awareness of the importance of range resources as a source of animal protein for the hungry peoples of the world, and (4) an enhanced understanding of the relationships between vegetation and environment, including climate as it influences vegetation production and changes over time. The realization of economic benefits, in terms of dollars and cents which would accrue from increased production, may be delayed until (1) an adequate number of image analysts can be trained to extract the kind of information from remote sensing data which can be applied to making on-the-ground decisions aimed at improving forage and animal production, and (2) data analysis techniques, which include automated image interpretation, can effect the rapid extraction of information useful for compiling practical land use and resource analyses

which can be used by range managers for planning and implementing range improvement, development and management practices. Fortunately, programs for training image analysts and for developing data analysis techniques have already begun, and within the next few years should prove indispensible in realizing the full benefit from remote sensing technology. Remote sensing in all of its modern ramifications may prove to be the most important technological advance to come to the range profession in this decade, for surely it holds the important key to success in an action program to increase human food production and solve resource use and management problems the world over.

SECTION THREE

Remote Sensing of Annual Grassland Range

The annual grassland of California is characterized by a dense cover of innumerable annual grasses, clovers and forbs. This mixture of species begins its annual growth cycle when seeds from the previous forage crop germinate, following the first soaking rains in the fall. Growth of the new plants is very slow during the winter months, but a rapid growth period occurs with the warming temperatures of spring. As early as March, but more commonly by April or May the plants reach maturity, produce seed and begin to dry. By the first of summer the annual vegetation is usually quite dry. This annual growth cycle is repeated year after year; however species composition, amount of herbage produced, and the timing of the various stages of development change almost in direct response to the amount and distribution of annual precipitation.

Because this open grassland type is an important source of forage for cattle, sheep and horses in California, as well as the Western U.S. and Mexico, and because a test site could be selected very close to the University of California, Berkeley (facilitating frequent observations requiring expenditure of little time or money), observation stations were established near San Pablo Reservoir (about 10 miles east of Berkeley, California) and study of this range vegetation using various kinds of film was initiated in June, 1965 (coinciding with the first NASA photographic mission of the San Pablo Reservoir Test Site). The interpretation of the photography from this first mission made it clear that in order to

maximize the information which could be extracted from the photographs, a more "optimum time" of the year would have to be selected. In addition, previous studies of annual grasslands by Colwell (1961) indicated that Ektachrome photography (scale 1/5,000) procured in the spring was most useful for evaluating animal carrying capacity. Thus during the 1966 growth cycle weekly observations of the development of the annual vegetation were made starting in April, 1966. The objective was to determine the usefulness of panchromatic, Aerographic Infrared (Wratten 89B), Ektachrome and Ektachrome Infrared (Wratten 12) photography for evaluating the condition of annual grassland range.

During this period important phenological changes occurred that are considered representative of the normal development of annual plants. These may be chronologically described as follows:

(1) By the first week in April, species occupying the upland slopes (characterized by shallow soils, from which moisture is depleted much earlier in the season) had begun to dry. The species mix on these slopes contained more clovers and forbs than grasses. At the same time, the annual vegetation (consisting mainly of grasses) occupying the bottomland sites (characterized by deeper soil which retains its moisture much longer in the season), was still very green since the seed heads were not fully developed and the plants had not yet reached maximum production. (Only general statements, such as the foregoing, can be made about the vegetation occupying a particular site because, by virtue of the number of different species, the timing of seed head production, maturing

and drying is not the same for each species).

(2) By the latter part of April the upland vegetation had nearly all dried. The bottomland vegetation was still green; however, seed heads had matured for most species and some of the plants were just beginning to dry. This seemed to be the optimum time for separating the upland sites, having considerably lower forage production, from the bottomland sites, having the highest forage production and grazing-capacity. Thus aerial photographs were taken (scale approximately 1/15,000) to show the appearance of the range at this date (April 27, 1966, see Figure 3.3).

(3) By the middle and latter part of May, only a few bottomland species remained green, the remainder having dried, thus obscuring those vegetation boundaries which only a month earlier were more representative of the upland or bottomland sites.

(4) By mid-June all of the palatable forage species had dried. Only a few scattered late-maturing forbs were still green. For the most part, the annual grassland range took on a dry, yellow-brown appearance. On the upland sites, where the production and density of the vegetation is lower than on bottomland sites, the combined effects of grazing and shattering of the dry plants left little residual dry matter as compared with that on the bottomland sites.

(5) By August scarcely a green plant could be found. Small scale aerial photography taken at this time confirmed ground observations that the range appeared homogeneously dry.

The results from this first year of observation were: Ektachrome Infrared film was best suited for detecting differences in site condition because the contrast in color between the healthy (green) and dry vegetation was accentuated on the infrared sensitive film type. Furthermore, the photography obtained at the time when vegetation on the upland sites was dry but still green on bottomland sites, was considered "optimum" for showing boundary lines between the different site conditions. Earlier in the season the range appears nearly homogeneously green and later a homogeneous dry yellow-brown. Although the scale of photography studied was only 1/15,000, it is possible to speculate that the separation of site conditions such as those existing in our study area could still be made at scales approaching 1/100,000. Black-and-white infrared film (0.7-1.0 u) was particularly good for detecting the presence of water in streams and ponds.

During the second year of observation (1967), interest centered on (1) the appearance of the annual range in a second consecutive year, (2) other types of information of use to a range manager that could be extracted from photography at other times of the year, and (3) applying this knowledge to practical applications of remote sensing from satellite vehicles.

Observations made during the second year include the following:

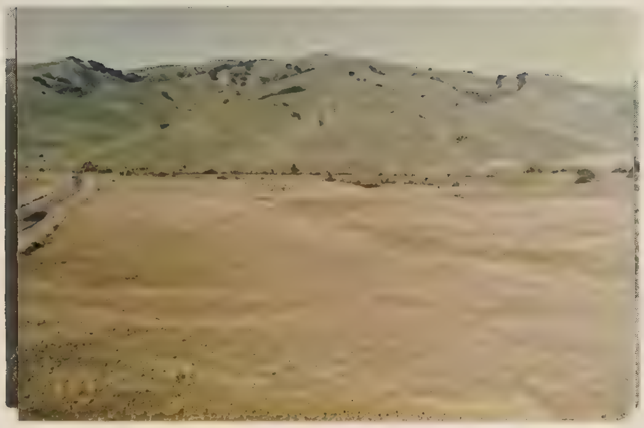
(1) During the early winter, new growth of annual vegetation is about 3 to 5 inches in length. Consequently on the upland sites the new growth overtops the residual vegetation, making the upland sites appear lush and green. At the same time, new growth

is partially obscured by the heavy amounts of residual dry material which was unutilized from the previous year's growth. Thus, bottomland sites do not appear as lush nor as green (see Figure 3.1).

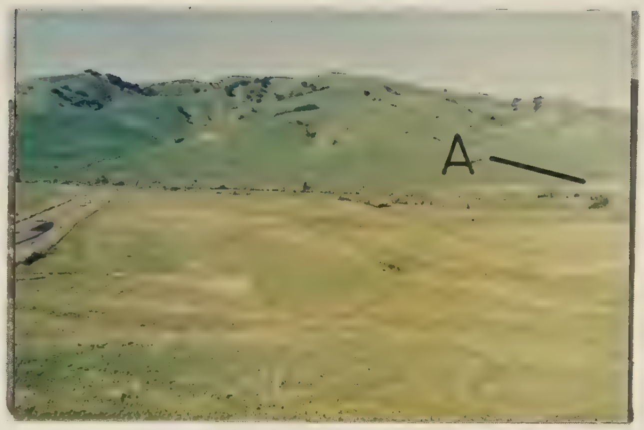
(2) About a month later (in February) new growth overtops the residual material and the annual grassland range takes on a near homogeneous appearance (figure 3.1, photos c, d).

(3) Later in the spring the upland sites again begin to dry as soil moisture is depleted, followed in turn by the drying of annual vegetation on the bottomland sites. In 1967, the total length of time required for this sequence to occur was about the same as during the previous year. However, in 1967 the maturing and drying of vegetation on the upland and bottomland sites occurred during May and June, instead of April and May as described for the previous year. (Compare the appearance of the range vegetation in 1966 and 1967 by referring to Figure 3.2). This phenomen~~a~~on was not unexpected, however, since the rainfall for the 1966-1967 growing season was more favorable (see Table 2) resulting in increased forage production and a prolonging of the green vegetative stage of plant growth. Furthermore, a more favorable species composition prevailed on upland sites (considerably more clover species were noted than in the previous year).

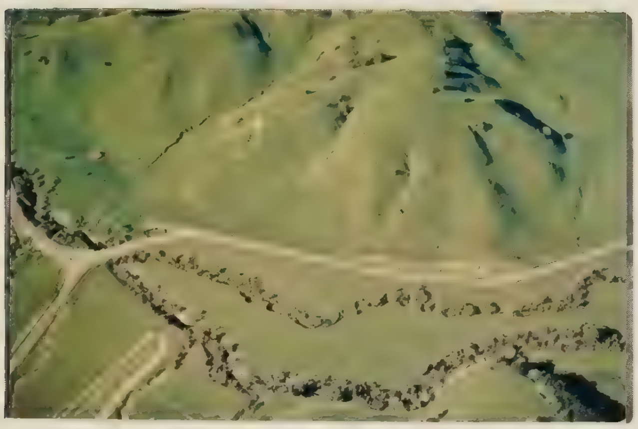
(4) By mid-June the upland vegetation was completely dry, and the bottomland vegetation was drying rapidly. Many of the annual grass plants remained green into July, but by mid-July the annual grassland range had again dried, taking on its characteristic



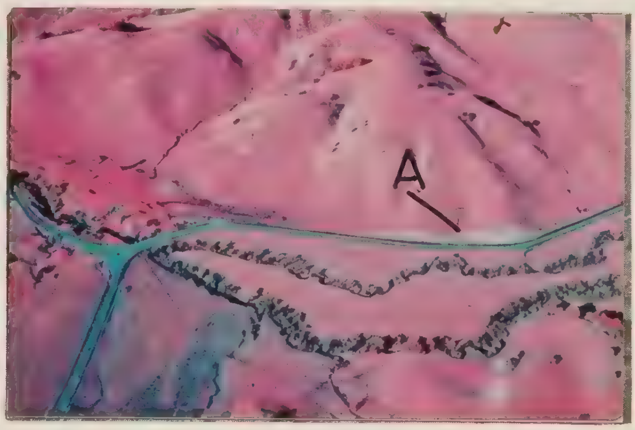
a) January 14, 1967



b) February 14, 1967

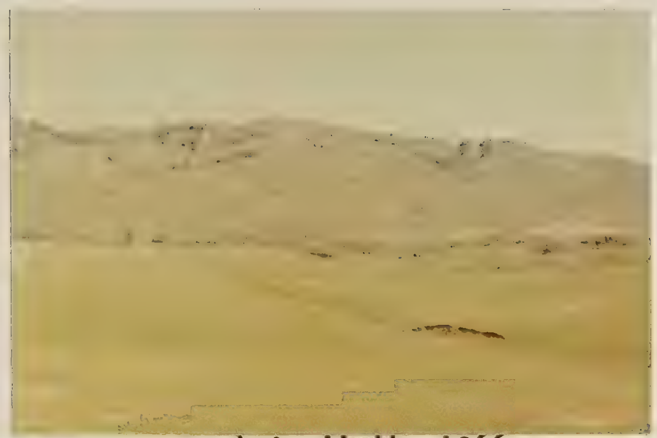


c) Kodachrome February, 1967



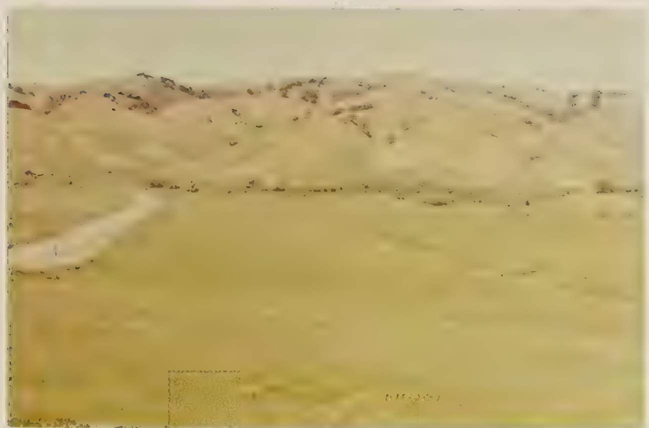
d) Ekta Aero Infrared Feb., 1967

Figure 3.1 The top photos typify the changing appearance of the annual grassland type in California, early in the growing season. In January, the "new growth", which is quite short, is often masked by the residual dry vegetation from the previous year, especially on good sites where considerably more herbage is produced than can be consumed by the grazing animals. Note that the upland sites usually appear greener because herbage production on these sites is not as great and the new growth overtops the residual material earlier in the season. A month later in February, the new vegetation has begun to overtop the residual dry material (in foreground) giving the annual range a nearly homogeneous "green carpet" appearance, as is evident in photo c. Because of this phenomena, aerial photographs taken at this time in the season are not optimum for differentiating areas of high and low productivity. Notice, however, the ease of detecting the residual material in an ungrazed area adjacent to the road (at A). This suggests that it may be possible to determine the relative grazing use, e.g., ungrazed, lightly grazed, moderately or heavily grazed, by noting the presence or absence of residual dry material on aerial photographs taken quite early in the growing season.



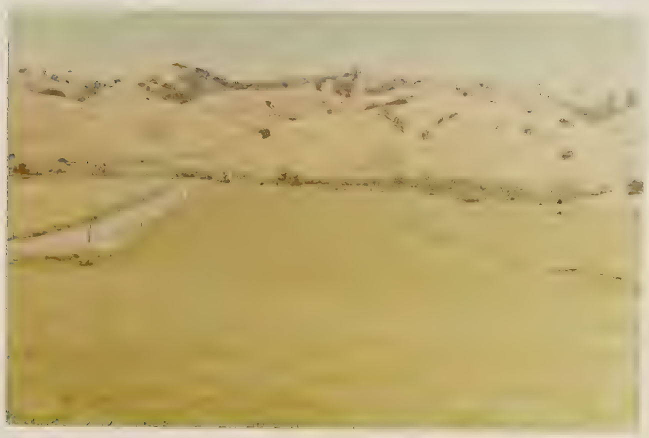
a) April 14, 1966

b) May 13, 1967



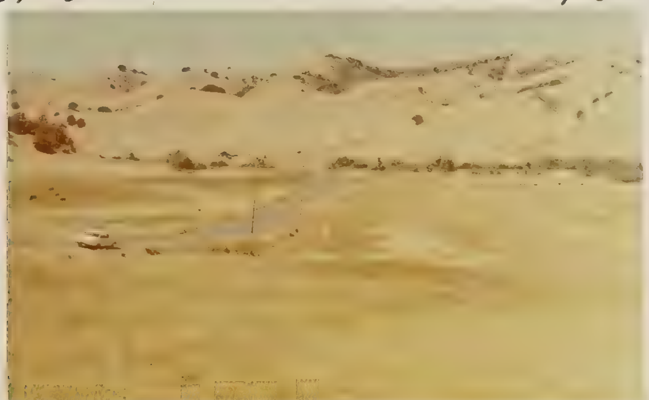
c) April 27, 1966

d) May 23, 1967



e) May 23, 1966

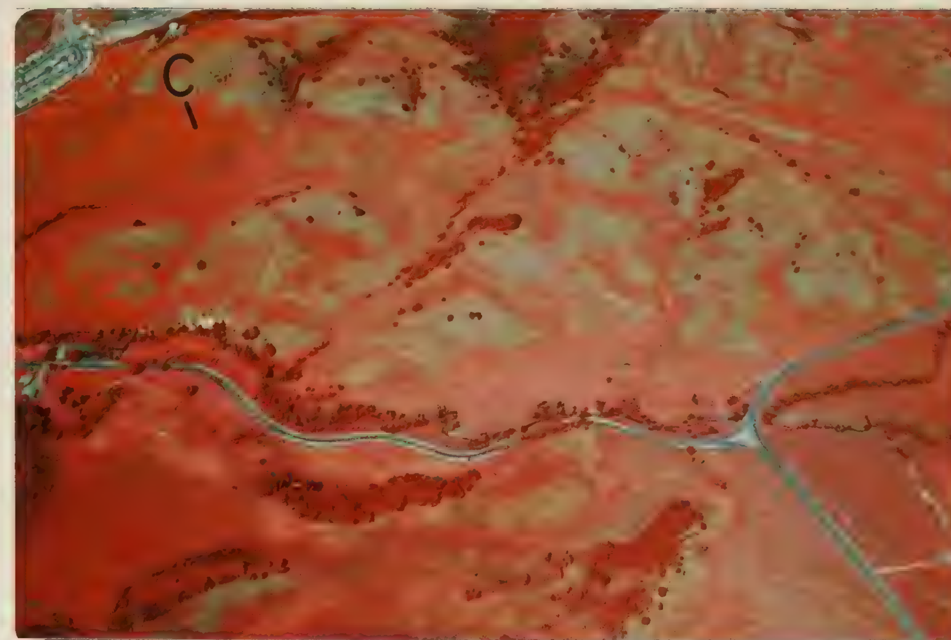
f) June 15, 1967



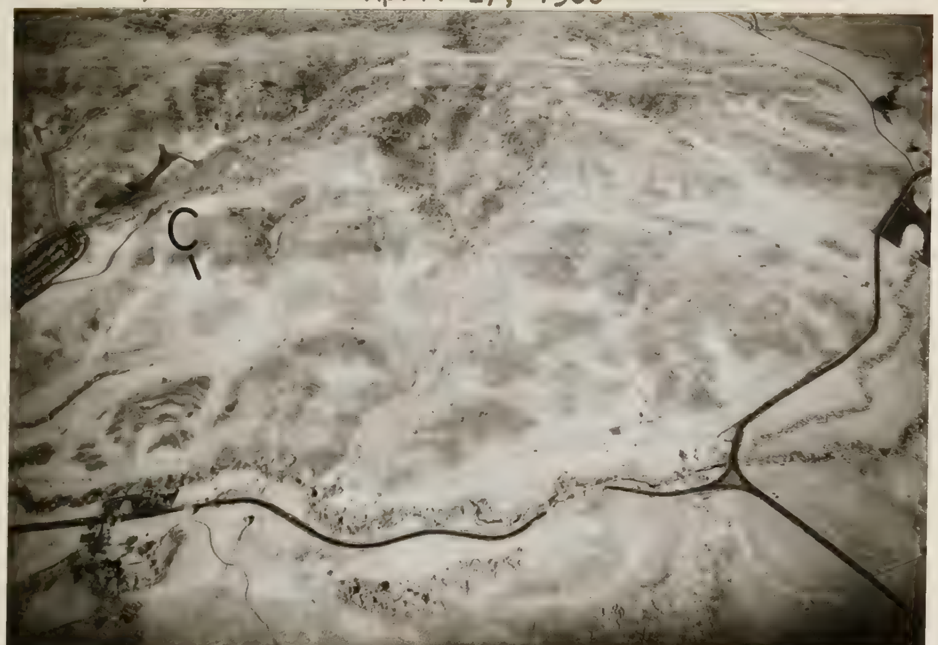
g) August 17, 1966

Figure 3.2 The sequence of photos shown above illustrates the changing appearance of annual grasslands in California (for two consecutive years) during the period when the annual plants begin to reach maturity, produce seed and subsequently dry. Notice that the vegetation on bottomland sites (having high carrying capacity) remains greener than upland sites (having lower carrying capacity). Photography obtained during this period would be optimum for stratifying these site conditions. Note also that the annual vegetation is greener for the year 1967, indicating that the annual vegetation received a more favorable amount and distribution of rainfall. For the significance of these types of interpretation, see text.

a) Kodacolor April 27, 1966



b) Ekta-Aero Infrared (Wratten 12) April 27, 1966



c) Black-and-White Infrared (Wratten 89B) April 27, 1966

d) Ground photo of the area indicated by a caret (V) in photo a.

Figure 3.3 The aerial photos above (a, b, c) were taken at the time of development of the annual vegetation considered optimum for differentiating sites of relatively high productivity (A) from sites having relatively low productivity (B). Note that at this time a legume species, vetch, is in full bloom and its presence and areal extent are readily seen at C. Identification of this species is important not only because it is a nutritious species but because it is a nitrogen fixer and enhances the fertility of the soil for grass production. The ground photo (photo d) shows a portion of the purple-flowered vetch, and also an area of soil slippage (center of photo).

Month	Monthly Precipitation, in inches	
	1965-1966	1966-1967
October	.05	.00
November	4.97	4.42
December	3.93	4.16
January	3.18	8.93
February	2.67	.42
March	.38	5.10
April	.51	4.82
May	.17	.13
June	.10	.84
Total for growing season	15.96	28.82

Table 2. Monthly precipitation during the growth cycle of annual grassland vegetation in test site, 10 miles east of Berkeley, California. Notice that the amount and distribution of rainfall during the growing season, 1966-67 is more favorable causing (1) a significant increase in forage production, and (2) a four week increase in available green feed. (The ppt. figures are the average of two gaging stations located east and west, respectively, of the test site; Data from Climatological Data, Vol. 69-71, U.S. Dept. Commerce, Environmental Science Services Admin.)

dry appearance.

The results of the second year of study confirmed several findings of the previous year and added very significantly to them. Specifically:

(1) Ektachrome Infrared film gives the highest contrast between dry vegetation and healthy vegetation and thus facilitates the differentiating of upland from bottomland sites. This does not preclude the possibility that panchromatic (Wratten 25A) and black-and-white infrared (Wratten 89B) films, when superimposed through image enhancement techniques, may be equally useful. As already indicated, black-and-white infrared photography is best for detecting stream courses and water bodies.

(2) The optimum time for obtaining photography is when most of the species on bottomland sites, although still green, have reached maximum production and are producing seed heads. By this time all range grasses on the upland sites have dried to a yellowish brown. This "optimum" time may occur in April or May depending upon the condition of the vegetation which varies in response to climatic conditions.

(3) It appears that Ektachrome or Ektachrome Infrared photography obtained early in the winter, e.g. December or January, may be useful for determining areas of greater or lesser amounts of residual dry material from the previous growing season. Using the amount of dry residual matter as an indicator, it may be possible to assess the amount of grazing use that a range had received in the previous year.

(4) A legume known as "vetch" (Vicia sp.), which is capable of fixing nitrogen in the soil and which provides nutritious forage for cattle, usually is readily detected on photography taken at the optimum spring date.

(5) Photography taken during two consecutive years provided an opportunity to observe changes in (a) the quantity of forage produced, (b) the timing of the various stages of development, and (c) the species composition, particularly where such changes were in direct response to the amount and distribution of annual rainfall.

Potential Applications of Satellite Imagery

When considering the potential applications of remote sensing techniques for the inventory of the world's range resources, the findings from studies of annual grasslands in California need not be confined solely to that particular area. For example, quite similar to the annual grassland type in California in morphological characteristics (e.g. density, height, seasonal change, etc.) are various kinds of savannah vegetation in other parts of the world, including (1) South America (e.g. the "llanos" of Venezuela or the "campos" of Brazil), (2) East Africa (e.g. Themeda-Hyparrhenia stands), and (3) Australia (e.g. the "downs" covered with Spinifex, Mulga and Mitchell grass). This statement is true notwithstanding the fact that savannah vegetation is predominantly perennial. Furthermore, savannah vegetation undergoes seasonal changes in appearance and condition (in response to climatic variation) similar to those of the annual grasslands in California. For

these reasons it is possible to draw upon results from studies of the annual grassland type in order to speculate upon practical world wide applications of imagery flown to proper specifications, from earth orbiting satellites.

(1) Space photography could be used to monitor the variation of forage production in response to climatic variation. According to Wahlen (1952):

> "the greatest single factor of instability in the exploitation of natural grasslands is their often extreme variation in seasonal production, which leads either to waste of fodder resources in the period of flush or to overstocking when the growth curve is low.... From the standpoint of competition between animal and man, there is no more wasteful procedure than accepting a yearly recurring hunger period for the animals as an inevitable part of livestock management."

This appears to be a world wide problem in the managing of range resources. By knowing the growth cycle of perennial or annual grasslands, one should be able to obtain photography at a time when (a) site differences can be distinguished, (b) seasonal production estimates can be made, and (c) predictions can be made of length of the remaining green feed period. This information when coordinated with ground sampling could then be utilized for predicting the length of time before supplemental feeds should be needed, livestock should be transported to market, in order to get the best price, or before the animals should be moved to other ranges, so that they do not damage the range by over-grazing.

(2) Space photography and related imagery could be used to monitor critical moisture conditions on rangelands. Many ranges

in the world receive prolonged rainfall in the wet season, causing flooding conditions on certain ranges. Heavy grazing too early on such ranges could cause severe damage to the forage resource. Satellites could detect these moisture conditions (e.g. using infrared sensitive films or sensors) and the time of grazing could be regulated accordingly. In addition, improvement of water supplies is an essential step to better utilization of natural grasslands. Satellite imagery can detect areas where perhaps, as a minimum, temporary supplies of water could be developed for more efficient use of large ranges.

(3) Space photography could be used to alleviate the problem of overgrazing, mainly by wild herbivores, in certain range areas and at specific times during the year (e.g. during the breeding and calving seasons). Satellite photos could show overgrazed areas and adjacent unused areas so that by the herding of animals, a better distribution of animals and a more efficient animal use of range forage could be achieved.

(4) Space photography could be used to identify range areas in which fire hazard reduction practices should be employed. Unused, residual forage can create a fire hazard on some ranges, which could jeopardize other important resources. On other ranges, fire is a most important tool for removing dry, residual forage to improve the quality of new growth. Satellite photos could monitor the extent of widespread burning on ranges.

(5) Over longer periods of time, satellite photography could be used to detect the encroachment of trees or brush onto

prime range areas. This encroachment may be an indicator of poor management practices. Considerable improvement of forage production could be realized by taking necessary steps to remove undesirable tree and brush species.

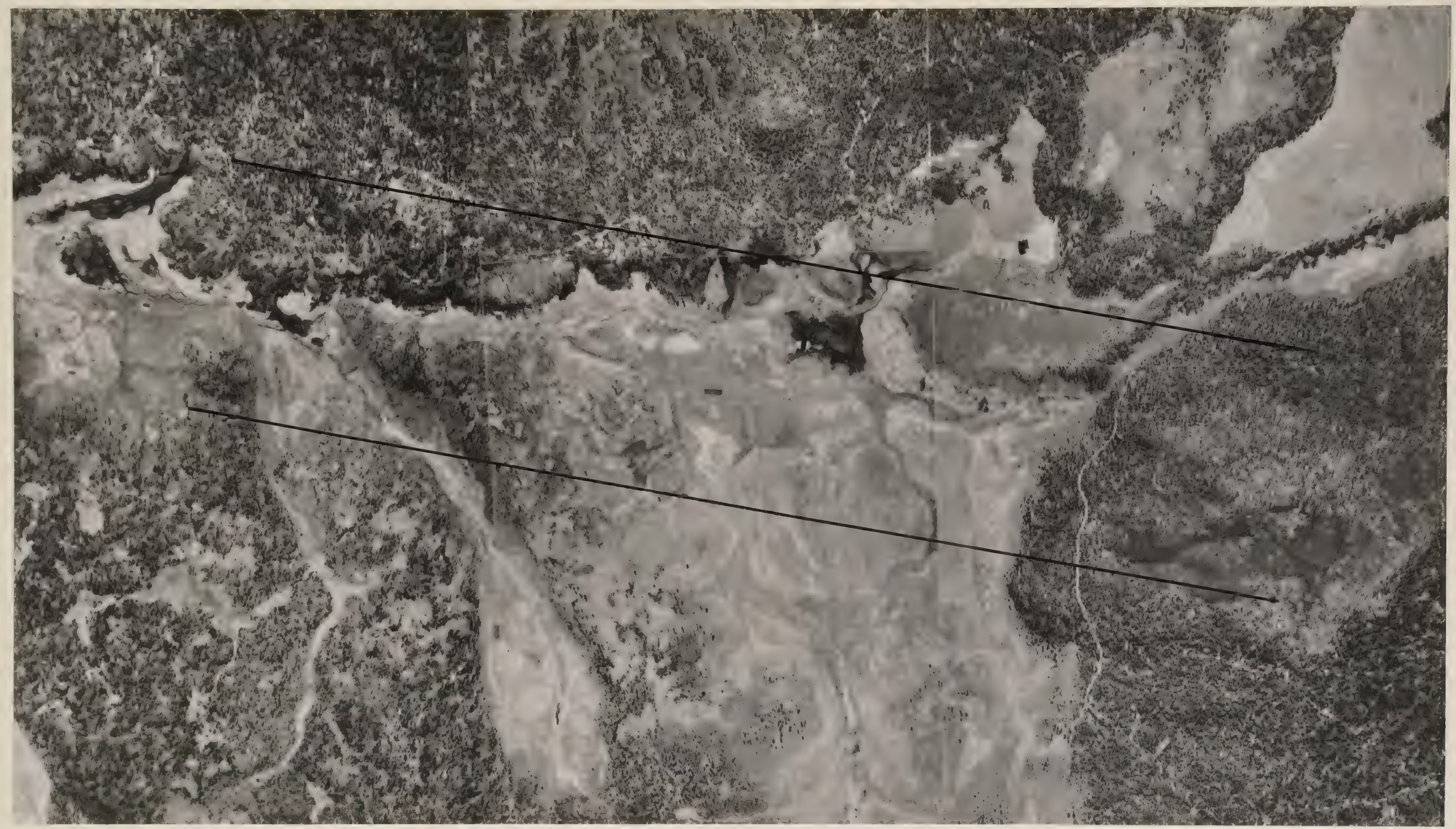


Figure 4.1 Photo mosaic of the Harvey Valley Range Allotment, NASA test site No. 135. This perennial sagebrush-bunchgrass range is located in the Southern Cascade Mountains, Lassen National Forest, California. Notice the diversity of soil, moisture and vegetation conditions on this small scale panchromatic photograph, dated October, 1954. The range land included between the inked lines is the study area for which multispectral photography and line scan imagery were examined and the vegetation-soil types mapped.

Evaluating Multispectral Photography

The conclusions of the 1966 investigation indicated that when a variety of vegetation types (such as those occurring at Harvey Valley), soil types and moisture regimes exist, Ektachrome infrared is the best single film type for detecting, identifying and evaluating the significant features. More specifically, Ektachrome Infrared film is particularly useful for:

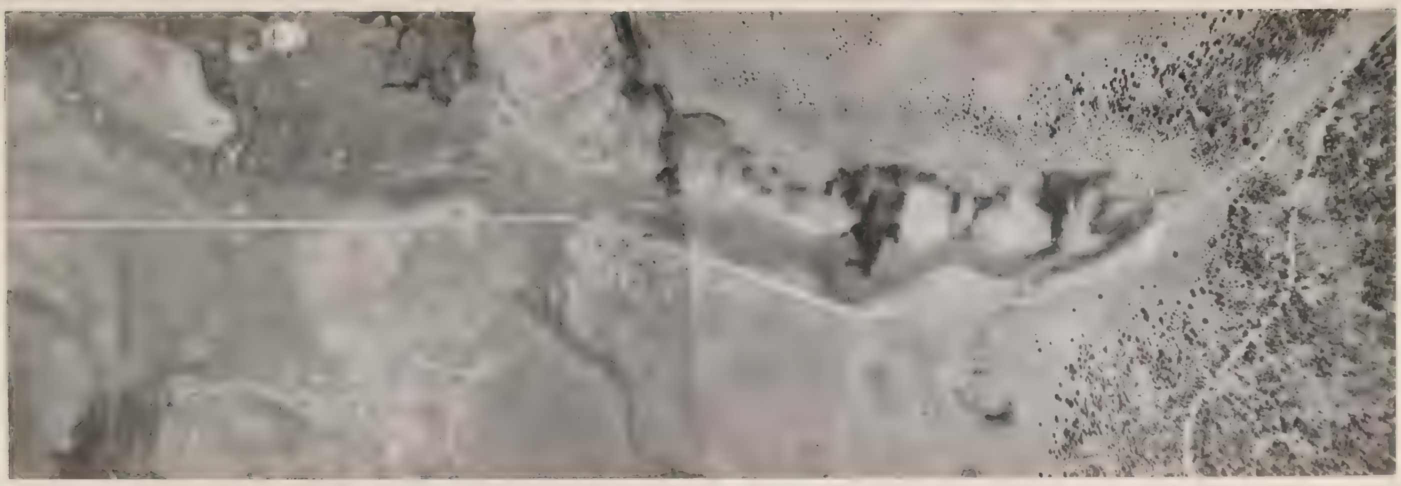
(1) detecting the presence and relative amount of foliage cover (of grass and brush vegetation) thus facilitating decisions concerning the placement of boundary lines between types which may have similar soils but different species composition and density. Ektachrome Infrared has limited use when the foliage cover of grass or low growing plants is so sparse that individual plants are not resolved. This point can not be overemphasized, for it has particular significance in view of the large portions of semi-arid regions, not only in the Western United States, but in dry areas in other continents, namely Africa, East Asia and Australia where use of this film type for inventory purposes would provide little useful information beyond that of conventional panchromatic photography.

(2)differentiating major species of brush or grasses. As an example, in Harvey Valley (and throughout the intermountain rangeland areas and throughout the Great Basin vegetation type) Bitterbrush (*Purshia tridentata*) and Big sagebrush (*Artemisia tridentata*) are important browse species. Bitterbrush is relished by cattle, deer and antelope, while Big sagebrush is used only on occasion by cattle and deer, but more frequently by antelope. These two brush species can be

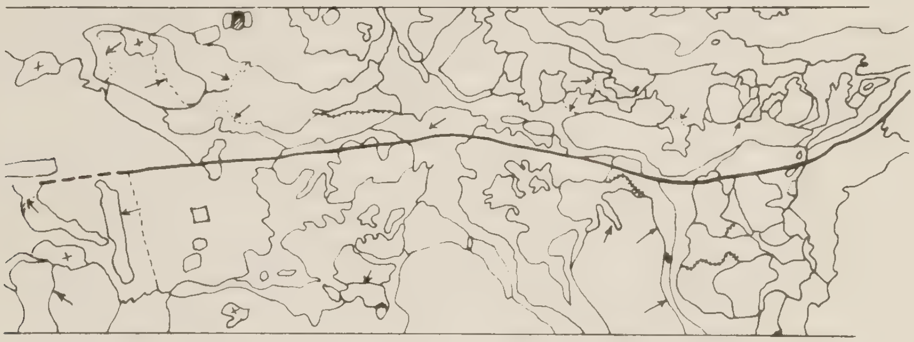
differentiated on Ektachrome infrared at scales up to 1/20,000; at smaller scales and with present limits of film resolution, the accuracy of distinguishing these species diminishes rapidly.

(3) detecting changes in soil surface characteristics (e.g., rock surfaces, gravel surfaces and texture differences) and moisture regimes (e.g., standing water, moist soil). The overall usefulness and/or limitations of Ektachrome Infrared film are attributable to its sensitivity to both visible and near infrared reflected radiation (.4-.9 microns). (Ektachrome infrared is a three layered film, two layers of which are sensitive to visible wavelengths of light while the third is sensitive to near infrared radiation). Because of this fact, it is in a sense similar to certain of the "color composites" that have been made by image enhancement techniques.

During the 1967 summer season, the research effort was concentrated on stratifying vegetation-soil boundaries on the four film-filter combinations previously mentioned. Delineation of boundaries was done in the office as carefully as possible and was followed by an examination of the boundaries and photography in the field. Drawing from the conclusions of this mapping effort, it is possible to rank the four film types in order of their increasing usefulness for mapping the soil-vegetation types in Harvey Valley (results would apply to scales 1/8500 to 1/25,000): black-and-white infrared, panchromatic, Ektachrome and Ektachrome Infrared. Figure 4.2 shows a panchromatic photo of the area on which the soil-vegetation mapping was performed. Below this is the soil-vegetation map which represents as accurately as possible the true boundaries as indicated by mapping on color and color infrared film



a) Panchromatic photography of test area in Harvey Valley



b) Vegetation-soil type map compiled from multispectral photography.

Figure 4.2 The panchromatic aerial photograph shows the test area in which soil-vegetation mapping was performed to determine which of four film types (panchromatic, black-and-white infrared, Aerial Ektachrome and Ektachrome Infrared film) was most useful for mapping the important plant communities. The type map shown in photo (b) shows the delineations made from panchromatic photography. However, corrections have been made by adding or deleting boundaries based upon the more accurate mapping that was possible from Ektachrome Infrared film. Notice that the arrows point to boundary lines which have been added or to boundary lines which were positively identified on Ektachrome infrared film. The boundary lines which have been lined out were incorrectly positioned boundaries made from the panchromatic photo which in fact do not exist. X's indicate entire types which were overlooked or not discerned on the panchromatic film, but were readily seen on the Ektachrome infrared photography. Notice how much more detailed this type map is than any of the type maps presented in Figure 4.3 which were made from optical mechanical scanner imagery.

coupled with ground checking in the field. Those areas which were difficult to map or were incorrectly mapped on the panchromatic photography are marked and a brief explanation is given in the figure caption.

The completed map differentiated (1) distinct plant communities, (2) plant communities which vary in density, and (3) changes in soil surface or moisture conditions. It also served as ground truth for evaluating the merits of 18-channel line-scan imagery obtained by the optical mechanical scanner for mapping complex native vegetation.

Evaluating 18 Channel Line-Scan Imagery

University of Michigan's optical mechanical scanner was flown over three flight strips (flight altitude--2000 feet above the datum) within the Harvey Valley Range Test Site between 10 and 11 a.m. on May 18, 1966. (At the same time, ground based teams were taking photographs and documenting the condition of vegetation and soil). By mid-summer this "classified" imagery was made available in film negative form for our examination and study. The wavelength ranges of these 18 channels were as follows:

Micron Range	Detector Used	Micron Range	Detector Used
.32 - .38	Photo Multiplier Tube	.72 - .80	Photo Multiplier Tube
.40 - .44		.80 - 1.5	"
.44 - .46	"	1.5 - 1.8	Filtered Indium - Antimonide
.46 - .48	"	2.0 - 2.6	
.48 - .50	"	3.0 - 4.1	"
.50 - .52	"	4.5 - 5.5	"
.52 - .55	"	8.0 - 14.0	Mercury-doped Germanium
.55 - .58	"		
.58 - .62	"		
.62 - .66	"		
.66 - .72	"		

In order to simplify the interpretation of this imagery from many different bands, only 12 of the original 18 channels were reproduced on photographic film. These included:

(1) five of the eleven bands in the visible portion of the spectrum (namely, .40 - .44, .46 - .48, .50 - .52, .55 - .58 and .62 - .66 microns). These visible bands selected are, arbitrarily, every other band.)

(2) one band in the ultraviolet region (.32 - .38 microns)

(3) two bands in the near infrared (.72 - .8 and .8 - 1.0 microns)

(4) one band intermediate between near infrared and far infrared (1.5 - 1.8 microns)

(5) three bands in the far infrared region (2 - 2.6, 3.0 - 4.1 and 8 - 14.0 microns).

After a preliminary examination of imagery from the 12 bands previously listed, the total number of bands examined was further reduced to five. This elimination process was based upon the following observations: (1) Spectral band .62 - .68 microns gave the best representation of soil-vegetation types of all bands in the visible spectrum, thus reducing 12 bands to 8 bands. (2) The 8 - 14 micron band appeared to be the most useful thermal infrared band, reducing 8 bands to 6 bands. (3) Since the .72 - .8 and .8-1.0 micron bands appeared similar, only the latter was chosen for study. This left the following five bands for more intensive study: .32 - .38, .62 - .66, .8 - 1.0, 1.5 - 1.8 and 8 - 14.0 microns.

Photo reproductions in the form of two-diameter enlargements of the original negative size were made of the five bands. On each of the respective photos soil-vegetation boundary lines were drawn on

acetate overlays. (The ground resolution of this line-scan imagery obtained at 2000 feet above the terrain was poorer than the ground resolution of the photography taken in June at a scale of 1/8500; consequently, vegetation typing was limited to recognition of tonal differences). Frequent reference to the original negative was necessary to delineate difficult areas because of poor contrast between adjacent types. Once the best type map was made, optical density of the negative for each type was determined using a Welch Densichron. Because of the variability of tone (resulting from variation of optical density of the negative) existing within types, as many as three to five measurements were made to obtain an average. However, a single average value is often unrealistic for representing a particular soil-vegetation type, because native vegetation types are characteristically heterogeneous; this is in contrast to agricultural crops which are by comparison more homogeneous. On the basis of the optical density measurements it was possible to determine on which of the bands the contrast between significant soil-vegetation types was greatest. At the time of this report,however, comparison of negative density values for the five bands under consideration was incomplete. Consequently, the following preliminary conclusions can be inferred from the studies of the five bands of line scan imagery:

(1) The greatest number of soil-vegetation types were discernible on the spectral band sensitive to red wavelengths (.62 - .68 microns). Therefore, this band was judged to be the most useful of the bands studied.

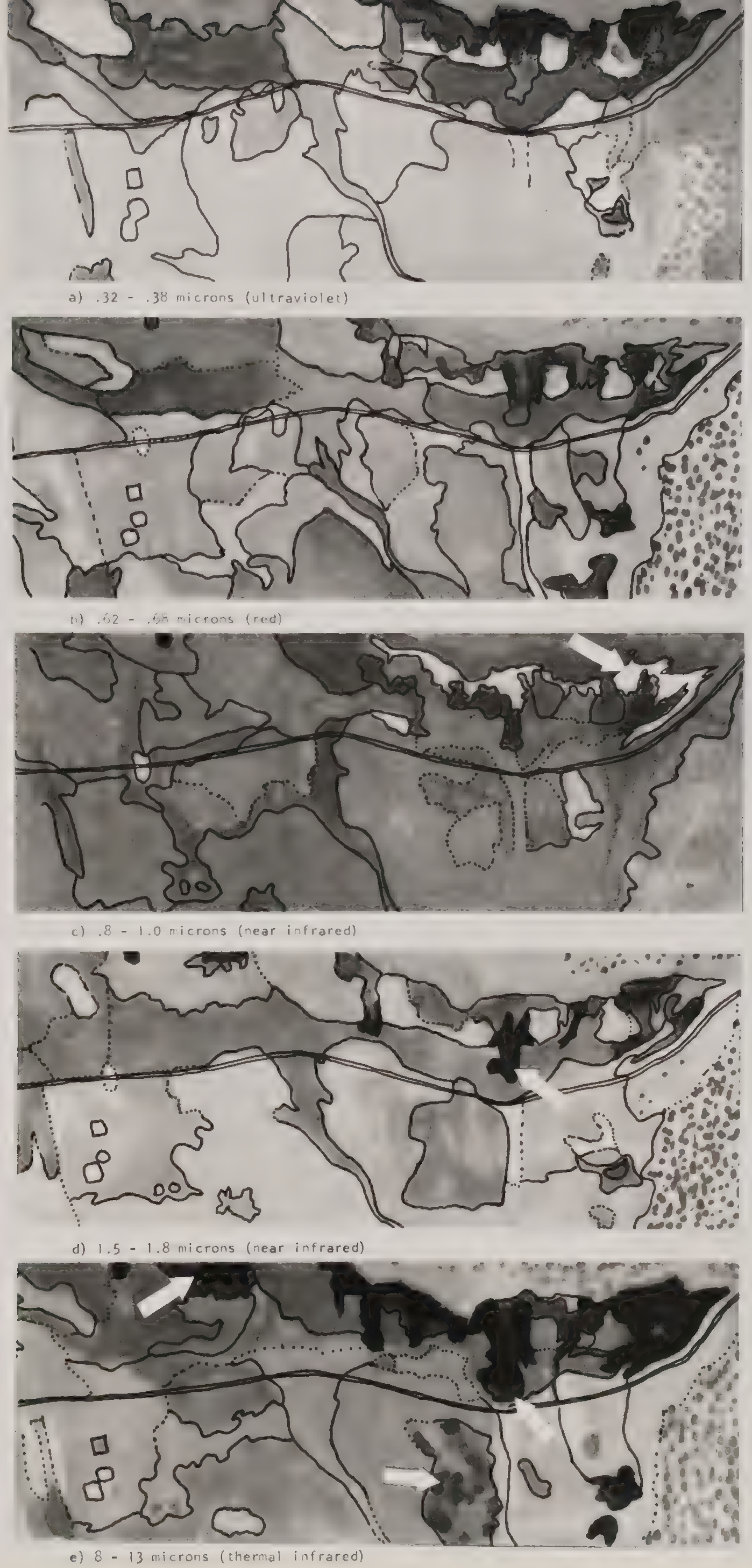
(2) Dense, lush grass and meadow vegetation was most readily

distinguished from all other features on the near infrared band (.8 - 1.0 microns). The .8 - 1.0 micron band seemed more responsive to the infrared reflection of the vegetation than did the .72 - .8 micron band.

(3) Moisture regimes (e.g., springs, areas of wet soil and areas where standing water was obscured from view by the vegetation) were best imaged on the 8 - 14.0 micron band. These phenomena were not observed on any of the other four bands under intensive study.

(4) An occasional soil-vegetation type was best seen on either the .32 - .38 or 1.5 - 1.8 micron band. In addition, a perimeter of standing water which crosses over boundary lines was best seen on the 1.5 - 1.8 micron band, but in general these two bands were not as useful in that they did not contribute enough additional information over that already provided by spectral bands in the visible portion of the spectrum.

Because of problems with military security, line scan imagery could not be reproduced in this report for general circulation; consequently, an artist's conception of the five line scan bands which have been discussed appears in Figure 4.3. The tone values in the illustrations are relative, as only a visual attempt was made to correlate tones with the optical density measurements for each type. Furthermore, these artist's conceptions do not show the within type variability which frequently was an aid in separating soil-vegetation types, especially when the overall tone was similar. The boundary lines indicated, however, are taken from the acetate overlays and represent the best type maps which could be made for each band. Note that in fact



a) .32 - .38 microns (ultraviolet)

b) .62 - .68 microns (red)

c) .8 - 1.0 microns (near infrared)

d) 1.5 - 1.8 microns (near infrared)

e) 8 - 13 microns (thermal infrared)

Figure 4.3 Artist conception of five bands of "classified" line-scan imagery obtained by an optical mechanical scanner. Notice that more soil-vegetation types are discerned on the band in the visible portion of the spectrum (photo b). The arrow in photo (c) points to the sharp boundary around meadow or dense grass vegetation. This near infrared band is particularly suited for distinguishing dense vegetation. The arrow in photo (d) points to the perimeter of standing water which is easily seen on 1.5-1.8 band imagery. On the thermal infrared image (photo e) the left arrow points to standing water covered by dense vegetation, the middle arrow points to a distinct type seen most readily on this type of imagery and the right arrow points to soil moisture not seen on the other bands.

the greatest number of types can be seen on the visible band and that it corresponds more closely to the type map in Figure 4.2 made from photos.

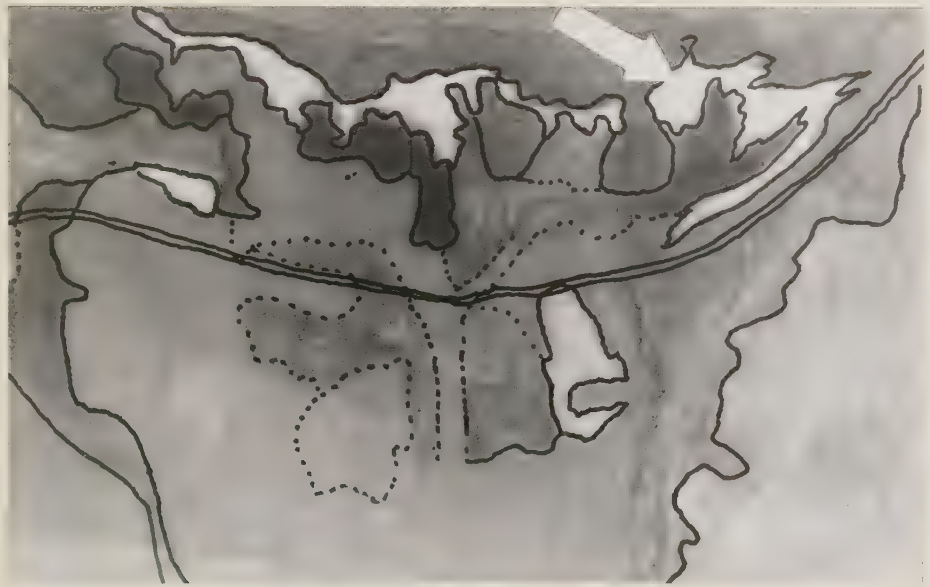
The near-common geometry of imagery obtained by an optical mechanical scanner can be an advantage to its interpretation by image enhancement techniques. Figure 4.4 illustrates a degraded "color composite" which was made by projecting three bands (namely, .32 - .38, .8 - 1.0 and 1.5 - 1.8 microns) through colored filters and in near common registry onto a screen. Differentiation of soil-vegetation types is noticeably more easy, even on this degraded image. Other combinations of bands have been made into color composites, but it is yet too early to report what combination of bands provides the most useful information.

Applications to a Resource Inventory from Space

The research emphasis at the Harvey Valley Test Site has been to examine various kinds of photography and other imagery (18 channel line scan imagery) in order to determine the usefulness and/or applicability of such imagery for inventorying range resources. From the foregoing results, it is apparent that images obtained with color films (i.e., Ektachrome and Ektachrome Infrared) at scales ranging from 1/8500 to 1/28,000 are more useful for mapping vegetation, soils and moisture conditions than those obtained with either panchromatic or black-and-white infrared film. How much better color film is than black-and-white film is difficult to answer. By conventional standards an acceptable job of mapping vagetation and soil types was done using only the panchromatic photography. However, what appears to be a more

a) Color composite of degraded line scan imagery.

b) .32 - .38 microns (ultraviolet)



c) .8 - 1.0 microns (near infrared)

d) 1.5 - 1.8 microns (infrared)

Figure 4.4 The "color composite" was made by projecting a .32 - .38 micron band line scan image through a blue Wratten 50 filter, a .8 - 1.0 micron band image through a red Wratten 72B filter, and a 1.5 - 1.8 micron band image through a green Wratten 99 filter. Artist's conception of the three bands projected appear above. Notice that color enhancement has increased the ease of recognizing the boundaries between the important plant communities. (Copies of the original line scan imagery can be sent to persons having the necessary security clearance).

important factor for making accurate type maps of native range vegetation in range areas is ground resolution. Native vegetation is frequently characterized by irregular patterns caused by the heterogeneity of individual plant communities; consequently, adequate ground resolution is a most important consideration when applying the results of this section to space oriented inventories.

Specifically, the photographic film types examined exhibited ground resolution ranging from 6 inches to 12 inches at a scale of 1/8500 and of three to four feet at a scale of 1/28,000. ~~And~~ For differentiating the important plant communities, the resolution of the smallest scale photography (1/28,000) was acceptable. However, the ground resolution of the line scan imagery, obtained at an altitude of 2000 feet above the average ground level was poorer than that of the small scale photography examined in this study. And although many useful range features may be discerned and vegetation-soil boundaries could be mapped by interpreting more than one of the many images obtained by the optical mechanical scanner flown at a low altitude, the limited resolution of this sensor may preclude its usefulness for making detailed vegetation-soil maps from orbital altitudes. Granted, the optical mechanical scanner can obtain simultaneous imagery in as many as 20 different bands, and the information can be processed rapidly by use of computers, as has been demonstrated for agricultural crop identification at the University of Michigan and at Purdue University. Still, if it cannot resolve sufficient detail to separate important plant communities at a level which would be useful for wildland managers, its value may be limited to other specific uses, e.g., agricultural crops.

On the other hand, because a great deal of the information required by range managers for making usable inventories depends upon adequate ground resolution, the highest resolution system that can be put into earth orbit will be the most desirable. Sensors with color film may have certain advantages (as discussed in Section Six); however, multi-layer films are not able to record as sharp an image as single layer black-and-white films. The ideal sensor may well be a multispectral camera with precision lenses which can collect wavelengths of light in the visible and near infrared bands of the spectrum and record the images on fine grained films. The resultant images would have the best ground resolution possible and could then be enhanced by image enhancement techniques, thereby maximizing the information which could be extracted from this type of sensor.

SECTION FIVE

Remote Sensing from Stationary Platforms

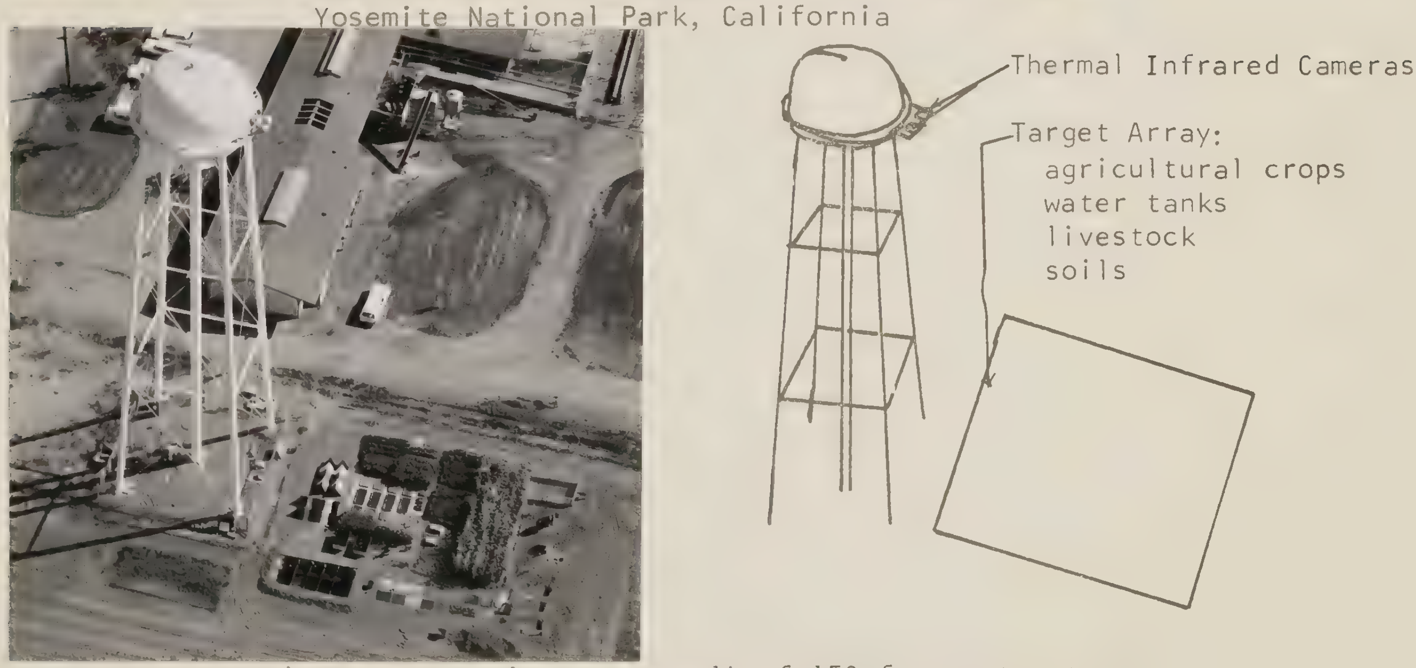
The studies discussed thus far have made use of photography and other imagery obtained from moving platforms -- primarily from fixed wing aircraft in flight. This section discusses studies of multispectral imagery obtained from stationary platforms. The first study that will be discussed in this section used as its camera platform the Glacier Point overlook in Yosemite National Park, California (see Figure 5.1). A second study, performed from the catwalk of a 150-foot water tower on the University of California campus, Davis, California, will be discussed later.

Three multispectral photographic experiments, each of about three days duration, were conducted from the Glacier Point overlook in June and September, 1966, and September, 1967. The objective of each of these experiments was to investigate the usefulness of multiband imagery for the inventory of wildland resources, each band of which had been taken with the same orientation and exhibited the same geometry. The imagery included not only photographs, but also thermograms that were obtained with a Barnes Thermal infrared camera. At each date the following type of photography and/or sensors were tested:

(1) a nearly complete series of filter combinations using Tri-X panchromatic film and taken with a Graflex camera having a long focal length lens (approx. 200 mm.).

(2) black-and-white infrared film exposed through a Wratten

a) Camera station on the Glacier Point Overlook
Yosemite National Park, California



b) Camera station on catwalk of 150 foot water tower
Davis, California

Figure 5.1 The top photo shows a stationary camera platform provided by the overlook at Glacier Point in Yosemite,National Park, California. The large instruments on the left and on the right are Barnes Engineering Thermal Infrared cameras which produce thermograms in the 8-14 micron and 3.5 - 5.5 micron bands of the spectrum (seen in Fig. 5.4). A long focal length Graflex camera used to take multispectral photos is seen between the infrared cameras. In the bottom photo, the stationary camera platform is a catwalk surrounding the 150 foot water tower located on the campus of the University of California, Davis. Beneath the water tower several kinds of targets have been assembled in order to evaluate their appearance on thermal infrared images and multispectral photographs. Stationary camera stations such as those shown above are advantageous for (1) testing various sensors and cameras, (2) obtaining imagery of similar geometry in several wavelength bands and at several times of day. This facilitates the making of color composites, employing color image enhancement techniques, such as the one seen in Figure 5.6.

89B filter, using the same Graflex camera.

(3) Ektachrome and Ektachrome Infrared films (the latter exposed through a Wratten 12 filter) using both a 35mm camera and the previously mentioned Graflex camera.

(4) Polaroid films on which thermograms could be registered through the use of two Barnes Engineering thermal infrared cameras. One of these cameras was filtered to detect emitted radiation in the 8-13 micron range; its detector was a thermistor bolometer. The other camera detected radiation in the 3.5-5.5 micron range; its detector was an indium antimonide crystal.

At each of the three dates, the photography was taken at a high sun angle, while the thermograms were obtained at regular intervals throughout the day and night. In addition, temperature measurements were made for the significant terrain features in the field of view, using either a surface temperature probe (YSI Model 42 SC Tele-Thermometer) or a "Precision Radiation Thermometer" (PRT-5), made by Barnes Engineering Company.

The PRT-5 instrument records absolute target radiance, which can be converted to actual target temperature by correcting for target emissivity and radiance of the background. The actual target temperatures may then be correlated with the apparent temperatures of objects as imaged on the thermograms. The apparent temperature~~s~~ of an object may be computed by a formula when the following data are known: density value for the object's image as seen on the thermogram negative; density values for various steps of a grey scale as imaged along one side of the same

negative; the internal detector temperature of the instrument; and the gain setting that was used on the instrument at the time the image was being formed. Thus the tone value of an object on a thermogram may be expressed in terms of its apparent temperature, and in turn this apparent temperature may be correlated with the actual temperature of the object as measured on the ground. For purposes of interpreting the thermograms, in many instances it was sufficient merely to recognize that relatively cool objects are dark, while relatively warm objects are light in tone.

The temperature variations of objects with respect to one another during a diurnal cycle provide an opportunity to differentiate among significant features, by virtue of their different thermal properties. The temperature fluctuations of soil, asphalt, meadow vegetation, forest vegetation, and water during a diurnal cycle (June, 1966) are represented by their respective diurnal temperature curves in Figure 5.2. By analyzing these curves it is possible to determine the optimum time of the day or night for obtaining thermograms on which to distinguish specific types of objects. As an example, meadow vegetation is the coolest feature during most of the night time hours. Consequently, it is the darkest feature seen on the thermograms taken during those hours (see Figures 5.4 and 5.5).

Notice that during most of the day time hours the Merced river is the coolest feature. It therefore appears as the darkest object on thermograms taken during those hours. It is of significance to observe that numerous thermal "cross-overs" occur.

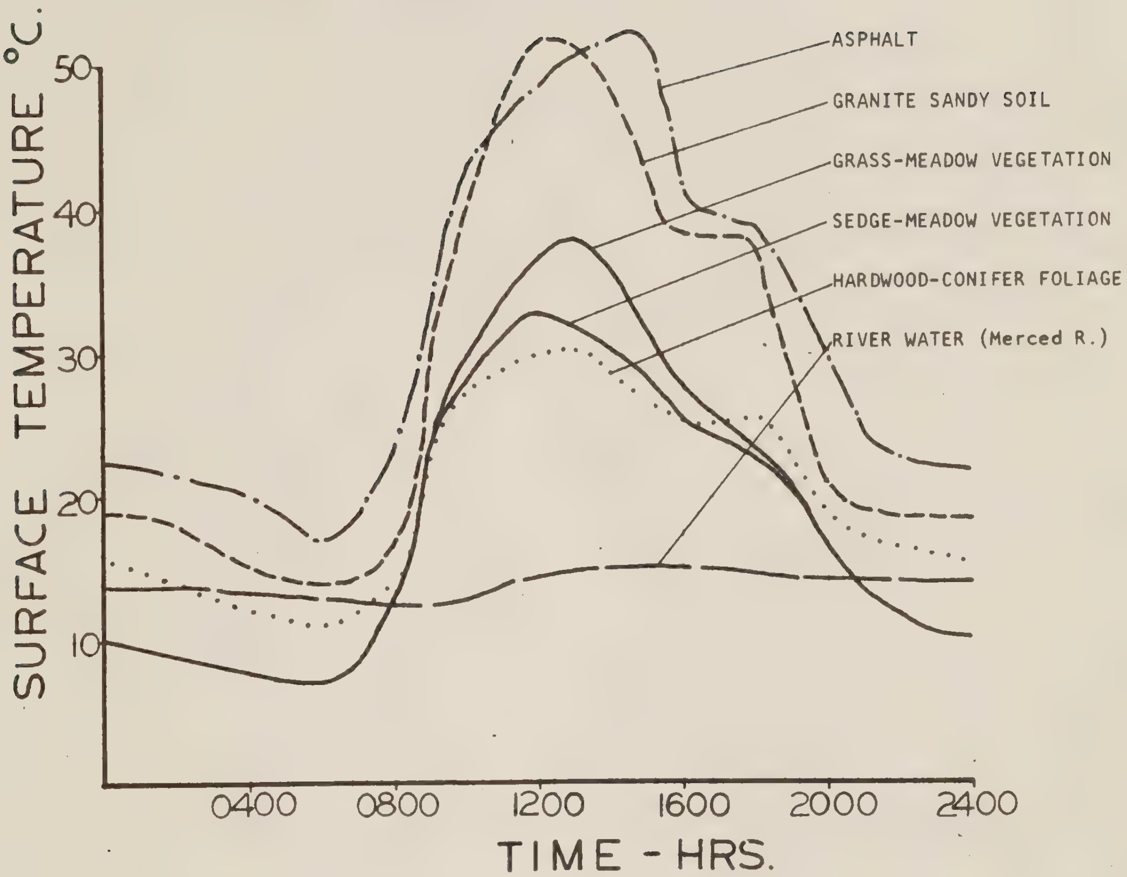


Figure 5.2 Graph showing the change in temperature of various terrain features during the diurnal cycle of June 20, 1966. These curves permit the reader to observe (1) relative temperature differences of objects at various times during the day and night, and (2) the relative rate of heating and cooling of objects. Surface temperature measurements of the various features were made at the same time that a Barnes Engineering Thermal Infrared camera was making thermograms (thermal infrared images in the 8 to 14 micron range) of the same terrain features. Consequently, interpretations from the thermogram can be supported by the temperature measurements made on the ground, and conversely, attempts can be made to predict the appearance (tone) of the various terrain features from an interpretation of the temperature curves. (It is recognized that tones depend not only on temperature, but also on emissivity.) For example, it can be predicted from the graph that the meadow vegetation should be darker than other features during the night time, but during the day, the Merced River should appear to be the darkest object (dark tones are indicative of cool temperatures). Similarly, asphalt and soil, which are consistently warmer than the other objects, will appear to be lighter than the other objects either day or night. The thermograms in Figure 5.4 were taken on June 20, 1966, at the same time that the above measurements were being made. The reader is encouraged to compare the tones of features at different times during the day with the temperature curve. For further interpretation of temperature curves, see text.

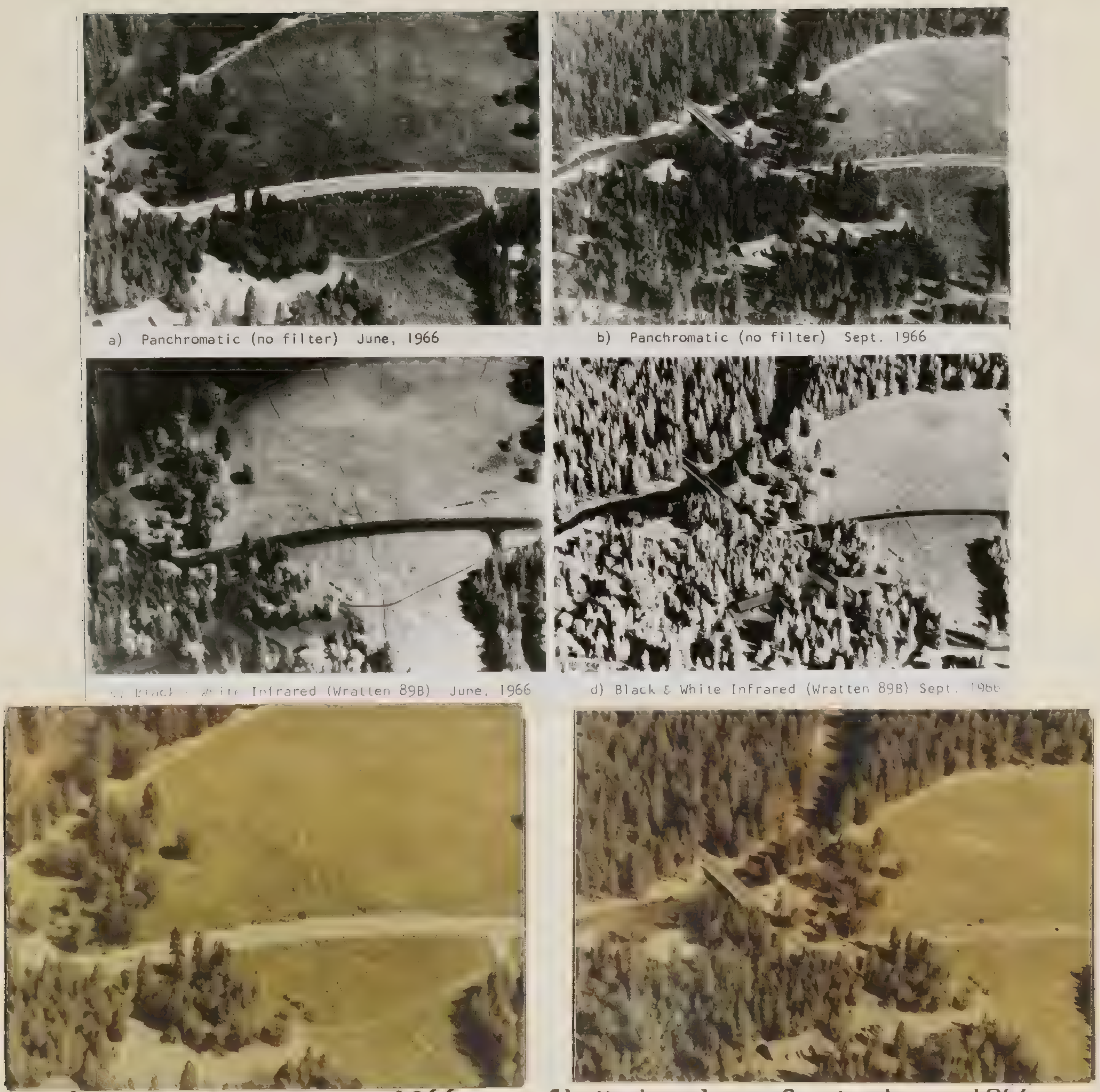
For example, meadow vegetation is cooler than water during the night but crosses over in temperature and becomes warmer than water during the day. This phenomenon can often be exploited to good advantage in making positive identifications of objects when thermal infrared imagery is obtained at two different times of day. As another example, conifer-hardwood vegetation exhibits a thermal cross-over with meadow vegetation. Therefore, the trees appear warmer at night and cooler during parts of the daytime with respect to the meadow vegetation. Consequently, if our objective were to separate forest vegetation from meadow vegetation, and the resolution of our sensor did not enable us to resolve sufficient detail to characterize either type, we could still make the distinction by obtaining imagery both at night and during the daytime; the forest vegetation appears lighter in tone than meadow vegetation on nighttime imagery, but darker in tone on daytime imagery. The reader is encouraged to examine this relationship on the thermogram sequence in Figure 5.4. It is also useful to note that in addition to the differences in amplitude characterizing temperature curves of features, the various objects attain temperature peaks at different times, and they heat up to or cool off from their peaks at different rates.

The same camera platform used in June was again used in September of the same season. This provided a convenient opportunity to study changes in the vegetation due to drying or trampling. If one compares the appearance of an ungrazed meadow on the floor of Yosemite Valley on panchromatic, black-and-white

infrared and Ektachrome photography (see Figure 5.3), he will observe such changes. It will be noted that the panchromatic and color films are useful for distinguishing many broad vegetation types in the meadow, while the black-and-white infrared film is useful for distingushing other vegetation types. In addition, this film is useful for differentiating hardwoods from conifers. It also will be noted that, on September photography, a specific plant community can be distinguished because it has dried earlier than adjacent plant communities. Besides the meadow vegetation being drier, a fall in the level of the Merced river can be detected.

The thermograms seen in Figure 5.5 illustrate how the meadow vegetation appeared in September, 1967. When a comparison between September, 1966 and September, 1967 imagery is made it is possible to conclude that neither the meadow vegetation nor the associated soil is as dry during September, 1967 as in the previous year. Rainfall data confirm the fact that considerably more moisture was available for growth in the summer of 1967 than 1966, resulting in greener conditions.

Since the same camera station was used on each of three different dates, all of the imagery obtained has the same geometry and orientation. For this reason it was ideal for "color image enhancement", a technique whereby image positives are simultaneously projected through selected colored filters and superimposed in common registration on a screen, thereby producing a "color composite". This color composite is (a) considerably more interpretable than



a) Panchromatic (no filter) June, 1966

b) Panchromatic (no filter) Sept. 1966

c) Black & White Infrared (Wratten 89B) June, 1966

d) Black & White Infrared (Wratten 89B) Sept. 1966

e) Kodacolor June, 1966

f) Kodacolor September, 1966

Figure 5.3 The photographs above covering part of the floor of Yosemite Valley, as viewed from Glacier Point, show the appearance of an ungrazed meadow at two different dates during the 1966 summer growing season. The reader should note that two broad meadow-vegetation types can be discerned on the panchromatic and Kodacolor photos taken in June. A community dominated by sedges (<u>Carex</u> <u>sp</u>.) occupies the lower meadow on either side of the road, and one dominated by grasses, but also containing various herbs and sedges, occupies the upper portions of the meadow. These two vegetation types, however, are very difficult to differentiate later in the season (see September photos) when the soil and vegetation have begun to dry. Note that in September a distinct plant community can be detected because it is much drier than adjacent plant communities. The infrared photos (photos c and d) differentiate the conifers (dark-toned trees) from the hardwoods (white-toned trees) at the edge of the meadow, but do not separate the two major meadow vegetation types. However, a distinct plant community consisting of broad-leaf forbs (at A) is evident on June and September black-and-white photos on either date. From this example, it can be inferred that (1) differences between major vegetation types may be detected more readily at specific dates during the growing season and (2) photos from more than one band in the e-m spectrum enhance the number of vegetation types and conditions which can be distinguished.

Figure 5.4 These thermograms taken in the 8-14 micron wavelength band show the changing thermal properties of vegetation, soil, asphalt and water during a diurnal cycle in June (left column) and September (right column). Dark tones on thermograms correspond to relatively cool objects while light tones correspond to warmer objects. These thermograms enable an interpreter to identify significant wildland features due to their characteristic appearance during a diurnal cycle or due to seasonal change. See text for interpretation of these thermograms.

a) 10:30 a.m. Sept. 8, 1967

b) 2:00 p.m. Sept 8, 1967

c) 5:00 p.m. Sept. 8, 1967

d) 9:30 p.m. Sept. 8, 1967

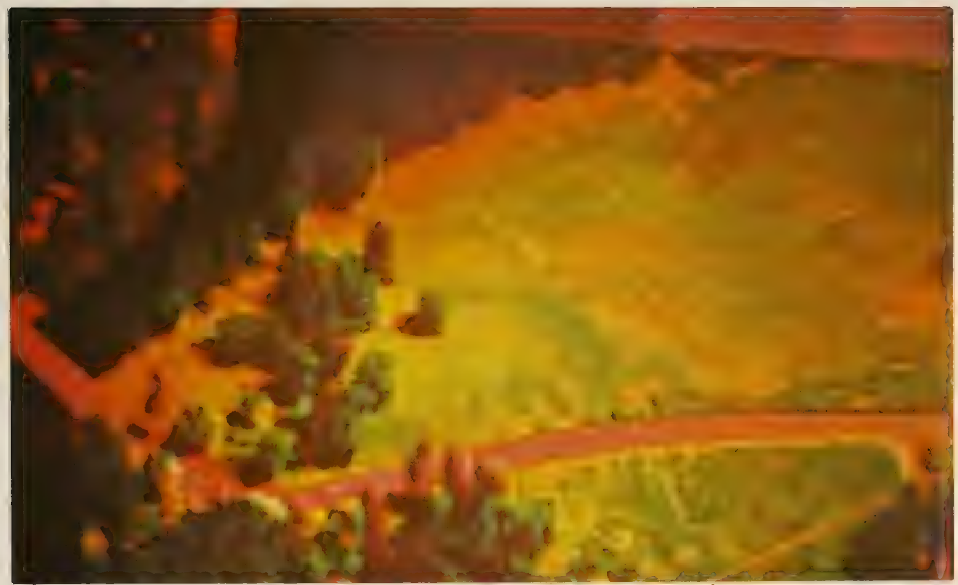
Figure 5.5 The sequence of thermograms (8-14 microns) shown above, taken from the Glacier Point overlook, at a distance of approximately 4000 feet, are among the many which were taken for the third time (Sept. 8, 1967) from the same stationary camera platform. Previous thermograms, obtained in June and September, 1966, permit an interpreter to (1) distinguish changes in the meadow conditions <u>within</u> a growing season (Fig. 5.4),(2)show changes of the meadow condition <u>between</u> growing seasons, compare Fig. 5.4 and 5.5. However, it was necessary to have the third sequence, shown above, to demonstrate that the temperature relationships between objects during a diurnal cycle are <u>repeatable</u> year after year.

any of the two or more images used to make the composite, and (b) more interpretable in certain respects than either Ektachrome or Ektachrome Infrared photography. Figure 5.6 shows an example of a color composite made by image enhancement techniques. In this case the three superimposed images include: a thermogram taken at 1:00 a.m.; a second thermogram taken at 10:30 a.m.; and a black-and-white infrared image also taken at about 10:30 a.m., all on the same day. Other color composites have been made using various film-filter combinations. Still others have been made using a thermogram (taken at 12 noon) from June, 1966, and a thermogram (taken at about the same time) from September, 1966. In this way it has been possible to observe seasonal changes in the vegetation on a single photo instead of having to interpret more than one image. One can speculate that it is feasible to superimpose images taken at the same season for each of several years and thus to analyze trends in vegetational change merely from the observation of colors on the composite image.

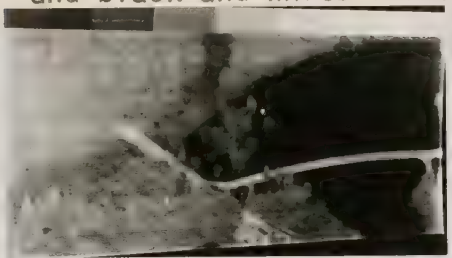
From these studies, which take advantage of a stationary camera platform overlooking Yosemite Valley, the following conclusions can be drawn:

(1) stationary camera platforms are useful for obtaining imagery on which important vegetational changes, both within season and between seasons, can be recorded. In addition diurnal changes, for example, of emitted radiation, can be studied.

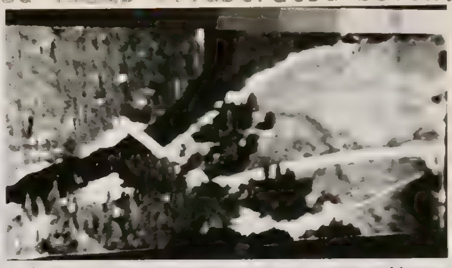
(2) imagery obtained at two different dates during a growing season (early and late) can be more useful for showing additional



a) Color composite derived from the two thermograms and black-and-white infrared image illustrated below.



b) Thermogram (8-14 u) 1:00 a.m., June 20, 1966



c) Thermogram 10:30 a.m., June 20, 1966

d) Black and White Infrared (.7-.9 u) June 20, 1966

Figure 5.6 The top photo is a "color composite" of the meadow which has appeared on Kodacolor, panchromatic and black-and-white infrared film, and thermograms in Figs. 5.3 - 5.5. This color composite is the result of projecting in common registration and through colored filters, the three black-and-white positive transparencies shown below. The 1:00 a.m. thermogram (photo b) was projected through a blue filter, the 10:30 a.m. thermogram (photo c) through a red filter and the black-and-white infrared image (photo d) through a green filter. This image enhancement technique has the primary advantage of increasing the quantity of information which can be extracted from a single photo, by superimposing images that are taken either at different times of the day or in different portions of the electromagnetic spectrum. For example, a sandy path (bright orange) is distinguished from meadow vegetation and an asphalt road because the path and vegetation are distinguishable on the 10:30 thermogram and the path and asphalt are separable on the 1:00 a.m. thermogram. Similarly, sedge vegetation in the meadow (deep green) is separated from the grass mixtures (mottled orange, yellow and greenish) because of the separations of these two types on the 10:30 thermogram. The conifers are separated from the hardwoods (bright green) because they are quite distinct on the black-and-white infrared image. For further explanation, see text.

kinds of plant communities occupying an area, than imagery taken on a single day.

(3) the condition of vegetation (i.e. greenness or dryness) from one season to the next can be compared on sequential imagery and certain inferences regarding the availability of moisture can be made.

(4) various kinds of imagery, having the same geometry and orientation, such as that taken from a single camera station, can be "color enhanced", thereby obtaining a color composite which is more interpretable than a single image. Furthermore, image enhancement techniques may have important application for studying vegetation changes within or between seasons.

(5) thermal infrared imagery (8-13 microns) obtained at selected times during the day and night can distinguish the following important features: meadow vegetation, forest vegetation, water, soil and asphalt. These separations can probably be made by exploiting differences in tone signature at different times of the day or night.

Multispectral photography and thermal infrared imagery also was obtained in a study performed from the catwalk of a water tower located near Davis, California. The target array for this study, performed on September 13-15, 1967, included agricultural crops (e.g. cotton, sugar beets, sweet potatoes, soy beans, sweet corn, milo and alfalfa), forest and agricultural soils, water tanks, and livestock. For the purposes of this report, the interest centered around the feasibility of using thermal infrared

sensors to detect animals. From imagery such as that shown in Figures 5.7 and 5.8 (and discussed in the accompanying captions), the following significant conclusions were drawn:

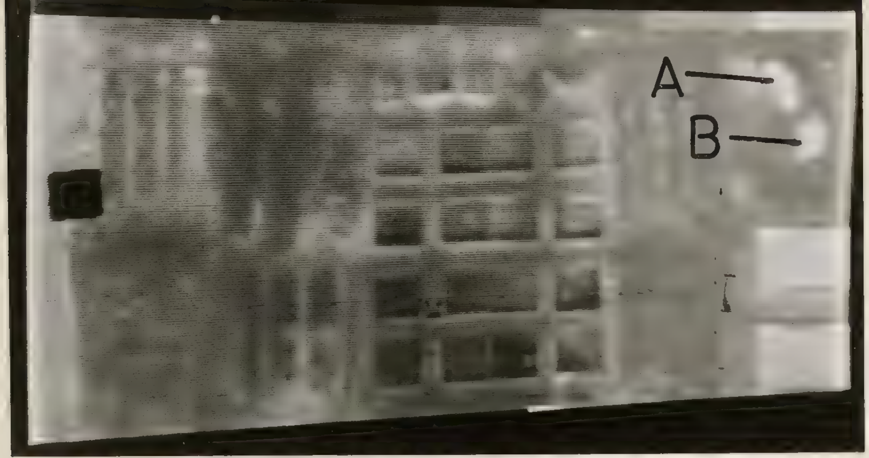
(1) Animals are readily detected on thermal infrared imagery, given the following conditions: (a) objects the size of animals can be resolved by the particular sensor. Using presently available infrared sensors, this means not exceeding 2000-3000 ft. altitude. (b) A sufficient temperature difference exists between the animal and its background; (c) The animals are not obscured from line-of-sight to the sensor by vegetation or other obstructions.

(2) A suitable time for detecting animals is in the early morning hours just before sunrise. At this time the animals can be detected on almost any background material. They can also be seen against a background of lush vegetation such as an irrigated pasture during most hours of the day and night.

(3) Striking differences between an unshorn sheep and a shorn sheep, and between an unshorn sheep and cattle were observed (see Figure 5.8). These observations suggest that more research is warranted to determine whether different species of livestock and/or wildlife can be distinguished under optimum conditions.

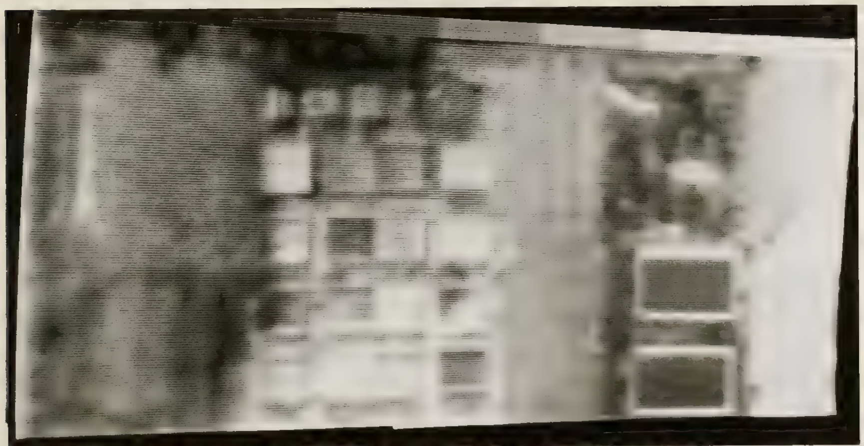
<u>Potential Applications of Satellite Imagery</u>

The limited resolution capabilities of available thermal infrared sensors is a deterrent to their usefulness from orbital altitudes. In spite of this it may still be possible to separate



a) Thermogram (8-14 u) 8:00 a.m. Sept. 14, 1967

b) Thermogram 3:00 p.m. Sept. 14, 1967



c) Thermogram 6:00 p.m. Sept. 14, 1967

Figure 5.7 These thermograms show a portion of a target array assembled below a 150-foot water tower at Davis, California. Included in this array are agricultural crops, forest and agricultural soils, water tanks (two in lower right of each thermogram) and livestock (a shorn sheep and Holstein calf appear just above the water tanks in upper ~~left~~ right corner of thermograms). The sheep (A) and calf (B) are most conspicuous on the thermograms taken early in the morning (photo a) because the vegetation and soil background material is cooler than the animals, creating a sufficient temperature difference that results in sharp contrast between the animal and its background. In the afternoon, however, the soil background heats up and it becomes difficult to detect the animals (photo b). If, however, the animals had been grazing in an alfalfa field or irrigated pasture which is relatively cool even in the afternoon, the chances for detecting animals would have improved. In the evening, as terrain features cool off, the animals become more detectable (photo c). Note, however, that the soil adjacent to the water tanks (along the right side of thermogram) is still relatively warm, which would make it difficult to detect animals if they were standing in this area. The results of this study suggest that animals can be detected on thermal infrared imagery (notwithstanding the resolution of the sensor) when a sufficient temperature difference exists between them and their background. The most likely period for detecting them is during early morning (before sunrise and at very low sun angle) and after sunset in the evening.

Thermogram (8-14 u) 11:00 p.m. Sept. 14, 1967

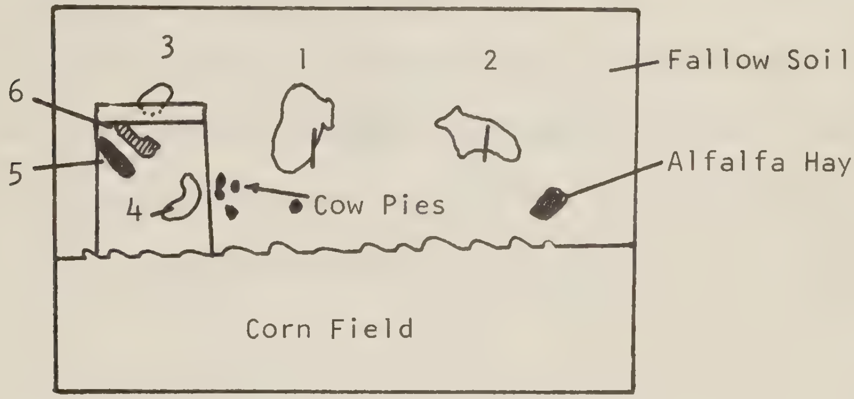


Figure 5.8 The thermogram above, taken with a Barnes Engineering Thermal Infrared camera, from the water tower at Davis, California, illustrates the potential use of thermal infrared sensors for inventorying livestock and wildlife. As is evident from the accompanying diagram. six animals are present in the thermogram: (1) a Holstein cow (mature), (2)a Hereford steer (approx. $1\frac{1}{2}$ yrs.), (3) a Jersey calf (partially hidden behind the corral fence), (4) a shorn sheep, (5) an old ewe with long wool, and (6) a young sheep with short wool. Absolute temperature measurements taken on the ground with a Precision Radiation Thermometer (PRT-5) at about the same time as the above thermogram, confirm that the long wool sheep was approximately 4 degrees cooler than the soil background; hence, it appears dark. The short wool sheep was about the same temperature as the soil and hence is difficult to detect, and the shorn sheep was approximately 10°C. warmer than the background soiland hence is much lighter in appearance than the soil. The shorn sheep, incidentally, was slightly warmer than the cow and the steer but this temperature difference is not evident from interpretation of this thermogram. It is conceivable that given an optimum time during the day or night and given a sensor that can be tuned to differentiate small temperature differences, that cattle and sheep could be distinguished from each other. Considerably more research is needed to examine similar relationships, not only among domesticated livestock, but among wild game animals as well.

gross types of vegetation, (e.g. tropical forest from savannah, or semi-desert vegetation from temperate forest). It may even be possible to monitor the moisture conditions of open grassland vegetation, especially in those regions of the world where flooding of range land is a common occurence during the wet season. It may also be possible to detect the areal distribution of rainfall for example in arid regions where lack of rainfall if a limiting factor in the production of forage.

The possibilities for increasing the interpretibility of black-and-white images by image enhancement techniques, lends credence to proposals for putting relatively high resolution multispectral cameras into earth orbit for inventorying earth resources.

SECTION SIX

The Feasibility of Analyzing Range and Related Resources From Gemini Color Photography

by

C. E. Poulton, E. H. Roberts, D. M. Carneggie

Introduction

As one reviews the work that has been performed, and the papers that have been written on the uses of satellite color photography for the mapping and inventory of world resources, it becomes evident that the native, nonforested vegetation types, the ranges of the world, have been given practically no attention; yet the forage and browse resources from range cover approximately one-half of the land area of the Earth. From this rangeland a tremendous renewable reservoir of cellulose and fiber is annually being converted to wool, hides and high quality protein for human consumption via the grazing animal--both domestic and wild. In view of the food problem facing the world's expanding population, it is inevitable that higher yields will be required of grazing, as well as agricultural land to meet the minimum food requirements of hungry people. The ranges of the world, if brought under more intensive management, could provide much of the needed animal protein for these hungry people.

Realizing the minimal attention given to range resources in NASA's whole space-oriented Earth Resources Program, the authors took advantage of a common interest and opportunity to consider, in greater depth than any have done to date, the feasibility of interpreting and mapping the characteristics of range areas from Gemini IV

color photography.

A group of five near vertical color photographs from Gemini IV, orbit 32, covering a large area in southwestern Arizona, were found to be exceptionally clear (due to absence of haze) and the color renditions provided an opportunity to differentiate gross vegetation and soil boundaries. With the availability of such promising photography, the expenditure of a few days in making a feasibility study seemed justified.

This initial effort is far from complete and it will continue as time and funds can be made available. This report should not be considered conclusive, but rather a feasibility report indicative of the uses, problems, and values derived from remote sensing of non-forested vegetation resources from space. We believe, however, that a report of progress to date would be most timely and useful since great attention currently is being given to the feasibility of making a comprehensive inventory of all Earth resources by the use of appropriate sensing devices operating from an orbiting platform.

Justification

Private and public land management agencies at the county, state and national levels have need for maps which provide accurate information relating to the present and best potential usage of the land. For wildland areas this involves making sound ecological interpretations based upon the relationship of major vegetation units to land form, soil characteristics and moisture regimes. A new technique for improving resource and land use maps is provided by space photography of high

quality and appropriate scale. Experienced managers, however, will be the first to point out that interpretations from present satellite photography cannot provide the kind of information needed for intensive management. It can, however, provide greatly improved information for (1) determining broad land use policy, (2) making preliminary decisions on the feasibility of certain land use conversions and major development programs, (3) providing a picture of resource interrelationships with cultural and economic development of an area, and (4) selecting areas for more intensive examination by other conventional methods.

An improved understanding of their natural resource base is needed by developing countries in the world. Considering the urgency of this need and the limited availability of manpower, the most feasible solution is to utilize remote sensing and carefully developed photo interpretation tehcniques, combined with the necessary amount of ground checking. For the most part, the developing countries do not initially need the large scale, intensive analysis that will become necessary as resource management, development and use intensifies. In many cases it would be a tremendous advantage and an economic savings just to be able, for example, to differentiate those areas having a potential for grazing or agricultural production from those lacking this potential. When and if it becomes feasible to put Earth Resource Satellites over developing countries, the U. S. can render a cooperative service to the world community of nations by providing the photographic base from which inventory of their natural resources can be made.

Procedure

Frames 9 through 13, from orbit 32, of the Gemini IV mission were obtained as color transparencies in 2 x 2 inch and 8 x 8 inch format, and as black-and-white prints on 11 x 11 inch format. Each photo in this series overlaps the next, thereby providing stereoscopic coverage of an area from Tucson, Arizona, east to the New Mexico state line. Most of the photo interpretation performed in the field was done on the 2 x 2 inch color transparencies. These were mounted on a small sheet of translucent plastic and viewed through a magnifying stereoscope. Attention was directed to specific vegetation and soil characteristics which had a unique appearance on the Gemini photographs. Interpretation in the field was measurably enhanced by stereoscopic viewing.

Because only two and one-half days were available for ground checking, an extensive circuit was traveled over major roads totaling 640 miles. Thomas P. Harlan supplied useful information on the vegetation at higher elevations which we were unable to visit. All of this information was recorded in relation to a mileage travel log and related to numbered ground truth stations. This made it possible to relate accurately the location of each station on a 1:250,000 USGS topographic map, and on the Gemini photography.

At selected stations, ground-truth photographs were taken with both Ektachrome and Aero Infrared Ektachrome films. Many of these photographs were taken as stereo pairs to enhance their value in subsequent examination. All photo stations were accurately located, pinpricked and labelled on one of the 11 x 11 inch black-and-white

enlargements of the Gemini photography. The ground truth data were collected at approximately 300 locations and ground photographs were taken at approximately 100 of these locations. A running travel log of vegetation characteristics, soil surface conditions, locations and nature of ecotones, resource uses and other relevant facts were recorded on a portable tape recorder. The ground truth records were transcribed to marginal, hand-sort punch cards by putting information from a single location onto a single card and using a separate card for describing the associated ground photos. Since there was a large number of ground truth records, these cards facilitate selection of desired records and summarization when large numbers of stations are involved.

Interpretations from Gemini Photography

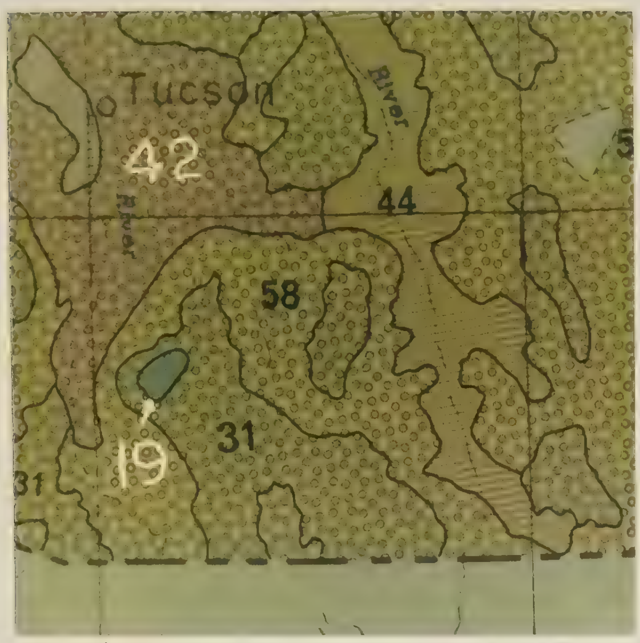
Even before the 19th century, man ~~has~~ recognized the need for mapping the vegetation resources of the world. One of the more recent attempts was by Kuchler (1964) who compiled an improved map of the potential natural vegetation in the contiguous 48 states (Figure 6.1). Because other means were not available, Kuchler did the work by traveling extensively, talking with knowledgable botanists and resource people, and compiling data from available large scale resource inventory maps--a laborious and costly task. In many areas this map represents an improvement over the work of Shantz and Zon (1928), but in some areas no improvement was possible. Humphrey (1963) has compiled a map showing the vegetation resources of Arizona (Figure 6.2).

Such maps have many uses, some of which are difficult even to anticipate, but their usefulness is dependent almost entirely upon the accuracy and completeness of the data presented. The possibility of using high quality earth-orbtial photography for the improvement of such maps is certainly worthy of investigation in view of the benefits to be realized.

The feasibility and limitations of using Gemini photography in the improvement of small scale vegetation and soil resource maps is best treated with illustrations. The reader is encouraged to compare an area from Kuchler's and from Humphrey's vegetation map with the corresponding area seen on the Gemini photograph (Figure 6.3). Additional illustrations provide an opportunity to observe the possibilities and problems encountered in making interpretations from small scale Gemini color photographs.

Needs to Which Space Photography is Suited

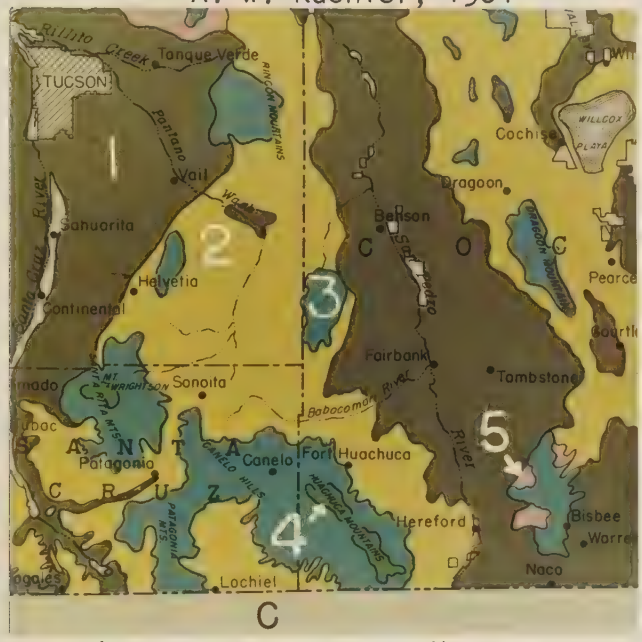
Some of the realistic needs which space photography might effectively help meet include the development of maps and analyses of vegetation resources on a small scale. Such products in turn are potentially useful: (1) in making county, state, and national land use policy statements, (2) in developing basic data where sequential coverage is a prerequisite to monitoring changes in the resource base, and (3) in selecting promising areas for closer examination by conventional aerial survey and/or ground methods for the purpose of solving various natural resource problems (for example, in locating areas into which developed agriculture could move as the population of the world seeks



Legend:

19. Arizona Pine Forest (Pinus)
31. Oak-Juniper Woodland (Quercus-Juniperus)
42. Creosote Bush - Bur Sage (Larrea - Fransaria)
44. Creosote Bush - Tarbush (Larrea - Flourensia)
58. Grama - Tobosa Shrubsteppe (Bouteloua - Hilaria - Larrea)

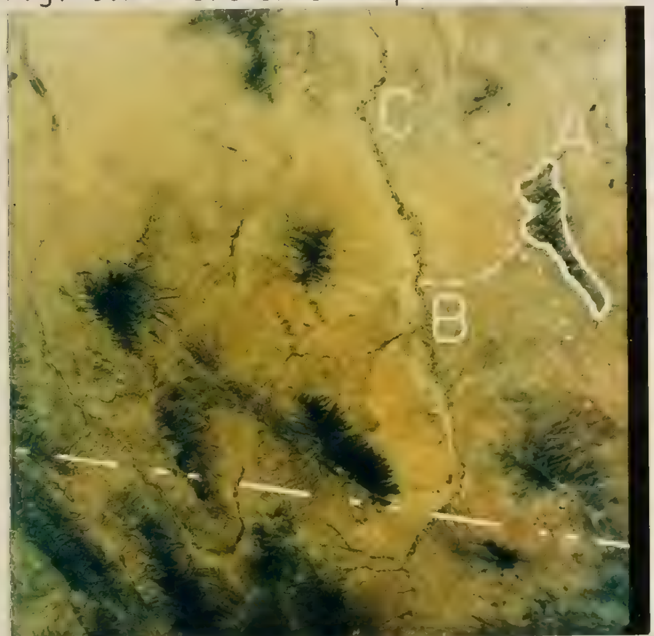
Fig. 6.1 Portion of map "Potential Natural Vegetation of the United States", A. W. Kuchler, 1964



Legend:

1. Southern Desert Scrub
2. Grassland
3. Juniper-Pinyon or Oak Woodland
4. Ponderosa Pine - Douglas Fir timber
5. Chaparral

Fig. 6.2 Portion of map "Arizona Natural Vegetation", R. R. Humphrey, 1963



Many of the obvious boundaries seen on the Gemini photography, (e.g. the area outlined at A) correspond closely with those seen on the two maps above. However, there are some apparent boundaries which show on the Gemini photo and do not show on the maps (e.g. at B); while others appear on the maps but not on the Gemini photograph (e.g. at C). In arid and semi-arid environments the openness of the vegetation permits the soil characteristics to be seen. As soil surface reflectivity and color varies, the image for highly similar vegetation varies. In order to avoid making considerable error when interpreting vegetation resources from satellite photography, an adequate program for subsampling with conventional aerial photography and collecting ground truth will have to be initiated.

Fig. 6.3 Photograph from Gemini IV. June 5, 1965

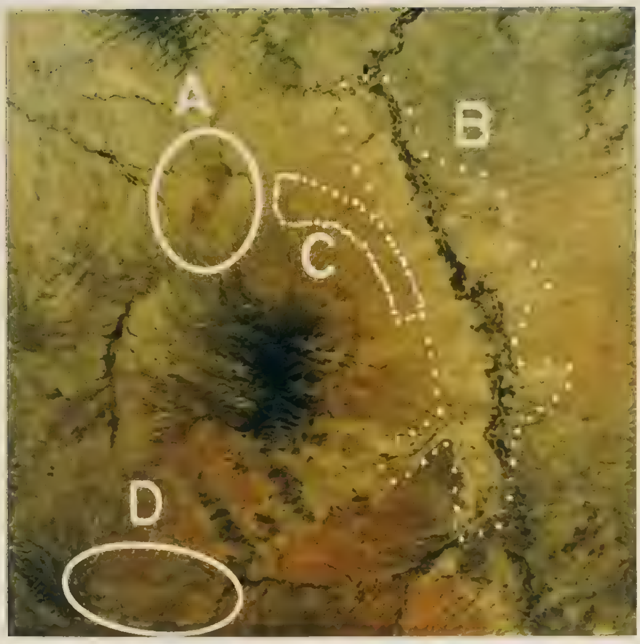


Figure 6.4 The area encircled at (A) shows a sharp transition of both soil and vegetation. In the darker areas, the dark gray color and the coarse surface texture of the soil, and the shrubby nature of the vegetation all contribute to give the darker tones on the photo. In comparison the soil in the surrounding area is reddish, the surface texture is smooth, and the vegetation is open grass and mesquite. The light tone within area (B) is exposed caliche, resulting from extremely rapid erosion of this area along the San Pedro River, beginning about 1890. The fisheries resource has been lost and the downstream water quality has deteriorated due to silting and increased flooding. Unstable land such as occurs along this river might be identified and considered in assessing the development potential of an area. At (C) an abandoned railroad grade can be seen. Although only about 20 feet wide, it is clearly visible because of its linearity. The coarse texture and dark color of the cinders combine to give this lower reflectivity and good color contrast with the surrounding terrain. At (D) can be seen a fence line boundary between public land to the north (upper) and a private ranch ownership to the south (lower). A lower density of brush in the species mix within the ranch ownership accounts for the visible change on the photograph.

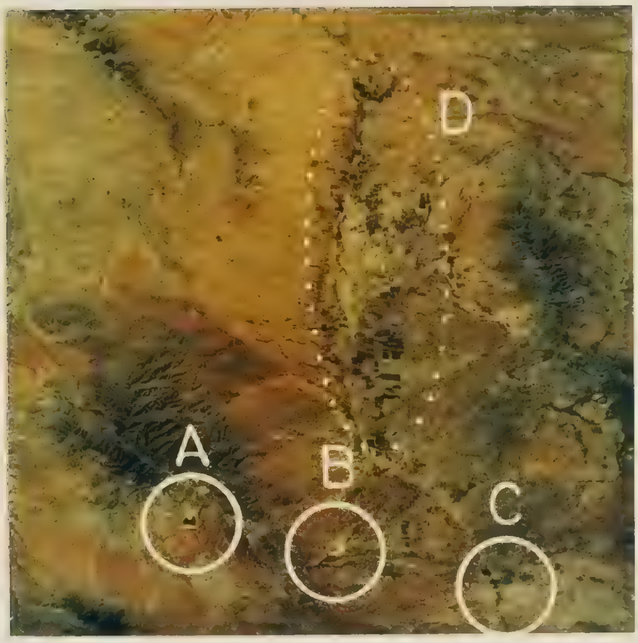


Figure 6.5 Many features in addition to the native vegetation and associated soils can be seen on satellite photography. For example, at (A) the conspicuous dark feature is an evaporation pond, approximately one mile square associated with the open pit copper mining operation seen directly above. Encircled at area (B) the light toned scar is that of a limestone quarry. Within area (C) smoke from smelters at the town of Douglas, Arizona can be seen. The smoke is also seen as it drifts eastward, i.e. to the right of the encircled area. Within the area of developed agriculture, marked (D), the dark rectangular areas are irrigated field crops. Notice that agricultural lands are readily seen, but towns or cities are often difficult to see (for instance, the cities of Douglas, Arizona and Aqua Prieta, Mexico, with a combined population of 30,000-40,000 are located within the encircled area, C).

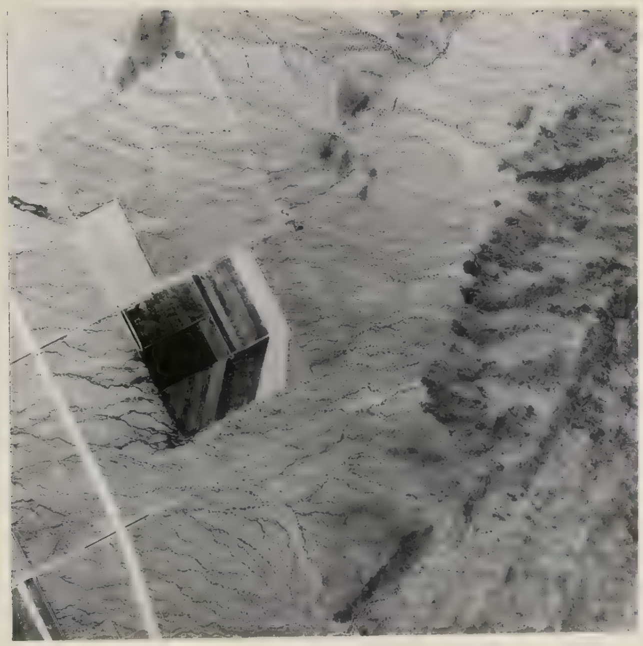


Figure 6.6 Satellite photography of adequate quality has an important use in detecting areas which are suitable, or most likely suitable, for development under higher or more productive land uses. An example is conversion from range use to cropland agriculture -- a consideration of great importance in developing nations and of increasing importance to all nations as population continues to grow. The conventional aerial photograph (left) shows area of native vegetation and cropland near Phoenix, Arizona, which is currently producing alfalfa due to the development of pump irrigation. Cotton and grain crops are also produced in this area. Notice that the vegetation and drainage patterns here are nearly the same as in the area labelled (A) on the Gemini photograph (right). Consequently, it may be inferred that if an adequate supply of water could be developed for irrigation of area (A), above, it also would be suitable for limited crop production. It may also become feasible, through interpretation of satellite photography and ground checking, to locate areas in which ground water can be found at reasonable pumping depths, and to identify those native vegetation types which could most profitably be converted to agricultural production. The interpretation of satellite photography obviously cannot answer the multitude of economic questions that would need to be considered in deciding whether or not to develop a particular area. However, it can provide a highly accurate picture of some of the relevant physical relationships such as the distances to existing market centers and the nature and location of transportation routes. At point (B) on the Gemini photo, a very dark volcanic soil type is responsible for the contrast with the surrounding terrain. (The area is appropriately named Black Butte). Nearby, the area marked (C) exhibits a similar dark tone, but in this instance the dark tone is due to a vegetation type, viz. a dense stand of mesquite (Prosopis sp.). At the two areas labelled (D), the scars of open pit mining can be seen.

to feed itself, or in detecting areas where agricultural cropping may have been overextended in relation to the ecological capability of the land). Through interpretation of the ecological characteristics of the land surfaces from space photography, it should be possible to meet these needs.

This expectation is realistic because native vegetation does in fact integrate all of the environmental factors, i.e,, soil, climate, geological influences and even the influences of man and animals, into an expression of the effectiveness of each kind of environment on the Earth's land surface. We can make use of such natural ecological phenomena to increase our understanding of the plant communities of the world if we learn to correlate photo image characteristics with the phytosociological indicators of analogous environments. Such an approach would provide a sound ecological base upon which to build our accumulating knowledge about renewable vegetation resources, productivity potentials, and man's use of resources. The same principles are applicable at all levels of intensity of resource analysis from the gross generalizations that are necessary when interpreting Gemini photography to the most refined and intricate detail that is needed for intensive wildland resource management.

Limitations and Advantages of Space Photography

On the basis of work performed to date, it can not be said that a panacea in small scale vegetation resource inventory and analysis can be achieved through the use of space photography. It should not even be inferred that accurate and useful ecological interpretation of vegetation can be made without much research in developing and analyzing

ground truth in relation to photo-image characteristics. However, the mere fact that an analysis of satellite imagery will permit the elimination of major areas from further consideration represents in itself a tremendous potential saving. As previously indicated, the success of a space photography program will depend largely upon the extent to which ground truth is coordinated with image interpretation. In spite of all the ecological work done in various parts of the United States, there is a notable dearth of research on the composition and structure of native plant communities, and on the relationships of each kind of vegetation to soil types and land forms. Herein lies one of the greatest limitations to the accurate interpretation of both aerial and space photography in this country. This problem will be an even more serious deterrent to the interpretation of satellite photographs of countries where phytosociological classifications of the vegetation resources have not been adequately developed. In many instances, this ecological understanding will have to be developed as a part of ground truth acquisition if the full potential of satellite photography is to be realized.

For those seeking to make an inventory of native vegetation resources, satellite photography should be regarded as a supplement to, and not as a substitute for, conventional aerial photography. A different level of information is expected from these two types of photography. From comparative studies of conventional aerial photography and satellite photography, it is apparent that ground resolution is a critical factor for accurately mapping native vegetation, while tone and color values are more important for evaluating agricultural

crops. However, where the objective is to develop maps showing only the regional or continental distribution of major ecological types of vegetation, limited ground resolution of Gemini photography does not appear to be a serious deterrent to its use.

The interpretability of native vegetation is strongly dependent upon the degree to which one can discern the internal structure of a particular plant community (i.e., the micro and macro geographic and vegetative patterns) and the boundary or ecotone, be it gradual or sharp, between plant communities. Whenever ground resolution drops to the point that plant communities are represented as single tones or colors, the accuracy of interpretations also diminishes. Failure to discern these internal patterns is the main reason why usefulness of this Gemini photography is restricted to depicting the regional distribution of major ecological types of vegetation.

Color film partially compensates for the loss of ground resolution because shifts in hue, brightness and saturation enable one to detect changes more readily than do shifts in gray tones. On the other side of the ledger, exposure and processing errors, and the variable effects of haze, make accurate interpretation of color photography from satellites a difficult task.

In spite of these technical limitations, some of the advantages to interpreting satellite photographs are:

(1) An image recorded from an orbiting platform can provide a true synoptic view and thus eliminate the between photo variables inherent in a photo mosaic.

(2) Large areas, for example entire continents, can be observed at essentially the same point in time. Furthermore, large areas can be mapped or studied on a single space photo.

(3) Sequential imagery could show seasonal changes; over longer periods, significant changes due to other factors, e.g., climate, land use, etc., could be observed.

(4) Imagery can be obtained of isolated areas where conventional aerial imagery would be difficult or impossible to obtain because of physical or political barriers.

(5) Gross vegetation-soil boundaries may be easier to discern because, at the small scale obtained, many of the gradual transitions appear to be sharpened or emphasized. Differentiation of the gross vegetation-soil units should make it possible to identify those areas with the highest potential for first order conversion to higher uses or to more intensive management.

(6) Resource data, when displayed directly upon satellite photography, permit relationships between vegetation resources, landforms and economic development to be discerned more easily than when presented by any other means.

This feasibility study has shown that in spite of certain limitations, many advantages can be realized from the interpretation of space photography. The specific techniques of mapping, and the accuracy of interpreting space photography, have yet to be determined. Additional research is surely required to provide the answers to these questions. This should be done before an operational earth resources satellite is put into orbit, and steps should be taken now to research

the relationships between ground truth and image characteristics. This would uncover additional problems, solve many that are known to exist and assure maximum benefit from an operational system for inventorying and/or monitoring earth resources from space platforms.

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SECTION SEVEN

Discussion and Summary

Before discussing photo specifications and other factors which will affect the interpretability of imagery, eventually to be obtained from space, let us consider one additional sensor which we have had only limited opportunity to examine. The sensor is "radar", which is an active system that provides its own source of energy. K-band imagery (wavelength in the 1-3 cm band) was obtained in October, 1965, for the Bucks Lake Forestry Test Site. Many meadow pastures could be seen on the radar imagery and it was possible to differentiate these meadowlands from adjacent forested land, due to tone and texture differences of the meadow image. From this limited study it was possible to conclude that radar may be a useful tool for mapping broad vegetation boundaries, especially because of its near all-weather capability and ability to obtain the same image night or day. More comprehensive studies of the application of radar imagery for identifying wildland and agricultural vegetation, are being conducted by NASA's radar team at C.R.E.S., University of Kansas. The results of their studies at Escalante Valley, Utah, and Horsefly Mountain, near Klammath Falls, Oregon, demonstrate that broad native soil-vegetation types can be identified and mapped (Morain, 1967; Moore and Simonett, 1967). However, the relatively low spatial resolution of the imagery obtained by radar sensors may limit its usefulness, especially from orbital altitudes, when detailed information is needed, e.g., for determining foliage cover, structure and composition, or for type mapping.

The studies discussed in this annual report examine <u>various kinds of photography and other imagery</u> (collected by a variety of sensors),

obtained at many <u>different scales</u> over a <u>variety of range environments</u>, and taken at <u>different seasons</u> and at <u>different times of the day</u>. From a study of this imagery, the most important considerations for developing photo specifications have been identified and examined. At the same time, we have begun to accumulate knowledge on which to make reasonable recommendations concerning (1) specifications of remote sensing systems to be put into orbit for the purpose of inventorying native vegatation resources, and (2) anticipated potential and practical applications which may accrue from such an orbiting vehicle if the capabilities of the system are known.

In considering specifications of a remote sensing system, one must first recognize the factors influencing image quality and image interpretability. The three factors commonly recognized are (1) image tone or color contrast, (2) image sharpness and (3) stereo parallax (Colwell, 1966). These factors affect not only imagery obtained from fixed wing aircraft, but also apply to imagery obtained from earth orbiting vehicles as well. If one examines each of these factors he finds it possible to list additional items which influence the above factors.

Those affecting <u>image tone or color contrast</u> are: characteristics of the film or filter, film processing, atmospheric conditions, spectral composition of light, goniometric effects (i.e., angular position of the sun, camera or sensor, or target object), temporal effects (seasonal changes, diurnal changes in solar energy, diurnal change in temperature of objects), polarization effects, spatial effects (orientation of objects with respect to other objects). Although all of the above items have important effects upon image tone or color contrast,

certain of them are of increased importance in view of the unique capabilities of orbiting vehicles. For example, atmospheric, goniometric and temporal effects may well be the most important factors affecting image tone or color contrast obtained from space. It is well known that, at any given time, large portions of the earth's surface are likely to be covered by clouds or other atmospheric conditions which may preclude procurement of interpretable imagery. However, there is good prospect that an orbiting vehicle might be in a suitable position for obtaining imagery at the time when atmospheric conditions are favorable. In that event, the wide swath width and the rapid speed of the space vehicle would permit a vast area to be covered in the short period during which weather conditions were favorable. Temporal and goniometric effects can be either an advantage or a disadvantage for interpreting space imagery. On the one hand, seasonal changes in vegetation and diurnal changes in sun angle can be exploited as advantages for increasing image identification; on the other hand, these same factors may create so much image variability in terms of tone and color that meaningful interpretations projected over large areas would be difficult to make. For example, Gemini space photos were taken over Arizona on two different dates, June and August. The terrain features appear quite different, and without knowing the ground truth conditions at the time each photo was taken, the interpreter would have a difficult task trying to determine if the difference could be attributed to (1) changes in the vegetation or soil over time, (2) sun angle effects resulting from obtaining the photos at different times of the day, or (3) differences in atmospheric condition. This suggests that

additional research will be needed to develop an understanding of image variability caused by temporal, goniometric and atmospheric effects.

Factors influencing image sharpness are: quality of the lenses, mirrors orother "collecting optics"; characteristics of the films or other detectors; photoscale; vibrations of the sensor system; and atmospheric conditions. Because imagery capable of providing suitably high resolution is needed in order to inventory earth resources, all of the above items must be carefully considered in selecting or recommending an optimum sensor to be put into earth orbit.

Stereo parallax is the third most important factor affecting the interpretability of conventional photography. The ability to view photos in this third dimension increases the ease of extracting information from the photo. However, from orbital altitudes, stereo parallax will be of limited use since the flying height is so great in relation to the height of features of interest that little parallax can be perceived.

Based upon previous research, including limited investigations of Gemini photography, and partly based upon speculation, it is possible to surmise that the highest ground resolution attainable from earth orbit will be prerequisite to a realization of the full value of satellite photography. Reference is made to the results reported in Section Six (Using Gemini photography for mapping vegetation and soil), where it was apparent that higher resolution, viz., greater than 300 to 400 feet, is needed to more accurately map even the broad vegetation types of importance to range resource managers. As was pointed out, many

vegetation boundaries were readily seen; however, there were enough major types which were not readily seen that better resolution is surely called for.

To summarize the foregoing, improved resolution from space can be achieved by improving upon (1) image tone or color contrast, and (2) image sharpness. This can be done to a certain extent by the appropriate selection of the sensing system. Therefore, if improvement of range resource inventories utilizing photography and other imagery from earth orbit, is our objective, it will require the high resolution which can be obtained only by camera and lens systems (at the present state of the art).

Based upon research performed to date, Ektachrome Infrared photography might seem like a logical choice of film type for an earth-orbital camera system. However, the resolution obtained from tri-layered films is not as high as can be obtained on a single layer, fine grained black-and-white film emulsion. Therefore, a multilens camera system which obtains high resolution images on black-and-white films which collectively are sensitive in the same micron range as Ektachrome Infrared (viz., green, red and near infrared) may be the optimum system initially for obtaining imagery from which immediate benefits could be derived. At the present state of the art (i.e., resolution obtainable by operational sensors) only limited benefits for improving range inventories are visualized by putting thermal infrared or radar sensors into orbit, although many practical applications using these sensors from either stationary platforms or from low flying fixed wing aircraft have been recognized. However, radar ~~sensors~~ may be a potentially

useful sensor when operated from earth orbital altitudes, especially over areas of persistent cloud cover. Even so, the limited resolution offered by radar imagery makes it of questionable use for mapping vegetation type boundaries even from conventional altitudes.

Finally, if it can be presumed that either the foregoing system, or one having similar capabilities, is put into orbit, the following applications for analyzing rangeland environments may be derived, given specified limits of resolution.

Given 300-400 foot resolution(such as is obtainable for terrain features seen on Gemini photographs):

1. Identification of regional forest land, brushland, grasslands and potential grazing land of the world.

2. Mapping of broad soil-vegetation boundaries. Special precaution may be needed in order to assure reasonable accuracy. Considerable ground checking will be a prerequisite.

3. Identification of features indicative of land conversion and/or land disturbance, e.g., erosion.

4. Location of areas which could feasibly be converted to higher or more intensive use.

5. Monitoring the seasonal development of vegetation in areas, e.g., annual grassland or savannah, where the vegetation forms a dense carpet over the soil mantle.

6. Identification of streams or water bodies or areas which could be developed for irrigation purposes.

7. Detection of moisture in the soil resulting from thunder showers, rain, snow, etc., especially in arid regions where moisture is limited.

8. Location of large bodies of standing water indicative of flooding conditions which occur on semi-tropical grasslands, and thus the evaluation of the suitability of the range for grazing, timed so as not to endanger the health of the plants.

Given 50-100 foot resolution (considerable improvement expected for detecting, identifying or evaluating the above items):

1. Mapping vegetation-soil boundaries found within large range areas with reasonable accuracy. Ground checking will still be quite essential.

2. Location of prime grazing land with respect to market centers and transportation routes.

3. Identification of springs or moisture areas which could be developed for livestock watering grounds.

4. Detection of areas which may have deteriorated as a result of overuse. Detection of different grazing use over large areas.

5. Identification of pure stands of species which exhibit striking phenological characteristics, and which cover large areas.

6. Monitoring the areal extent of recently burned rangelands.

Given 10-25 foot resolution (considerable improvement expected for detecting, identifying and evaluating the above items):

1. Mapping and classification of vegetation-soil types.

2. Evaluation of relative foliage density and vegetation structure.

3. Evaluation of site (production) differences.

4. Evaluation of plant health during the growing season.

5. Limited species identification.

6. Evaluation of soil moisture conditions.

7. Limited evaluation of soil surface characteristics.

It should be reemphasized that space photography is a supplement to and not a substitute for conventional photography. Hence, an inventory procedure which utilizes both space and fixed wing aerial photography would increase the benefits and in a sense minimize the importance of initially procuring high resolution photography from space vehicles.

Summary and Conclusions

Remote sensing is an extremely useful technique for inventorying rangeland resources. The studies reported herein dealth with both annual grassland range and perennial bunchgrass range as imaged on space photography, aerial photography and imagery obtained from stationary platforms in various portions of the electromagnetic spectrum. From these studies it is apparent that multiband photography and related imagery obtained from air and space can provide valuable information for use by range managers for improving their resource inventories. Of the four conventional film types examined, Ektachrome Infrared photography was most useful for mapping vegetation, soil and moisture conditions in range environments where foliage cover is high, or where various kinds of plant communities having both high and low density occur in the same region. However, there is considerable merit to obtaining high resolution panchromatic and black-and-white infrared photography, to be interpreted in concert or to be optically combined by image enhancement techniques.

Preliminary studies of 18-channel line-scan imagery, while they were not complete, indicated that when using an entirely black-and-white multiple band system, bands in the visible portion of the spectrum were most useful for differentiating vegetation-soil boundaries. However, bands sensitive to near infrared wavelengths were useful for positive identification of two specific vegetation types, meadow vegetation and dense grass cover. Thermal infrared imagery (8-14 microns) was useful for detecting soil moisture conditions and standing water beneath a vegetation cover. Such conditions were not discerned on other bands.

Other bands, e.g., 1.5 - 1.8 and .32 - .38 microns, were useful for identifying a few specific vegetation-soil boundaries, but in general were not as useful as bands in the visible portion of the spectrum.

The relatively low resolution presently obtainable from optical mechanical scanners may initially limit their usefulness for mapping rangeland resources from earth orbiting vehicles, although many practical applications from low flying aircraft are recognized. Radar sensors may prove to be useful over areas of persistent cloud cover if their resolution characteristics are improved.

Based upon the research performed under this NASA-sponsored program, recommendation is made for a 3-lens, 3-band camera system, filtered for sensitivity in the green (.5 - .58), red (.62 - .66) and near infrared (.8 - 1.0) wavelength regions, respectively. This system is considered to be the best currently available for making improved inventories of native range vegetation. Color composites could be made from the resulting black-and-white images having the same geometry, thereby facilitating image analysis and maximizing the available information.

Anticipated range resource applications of space photography having prescribed resolution limits are given earlier in this section. Based upon these potential applications, world wide range resource inventories can be improved, especially in developing countries. At present such countries lack the basic inventory data needed for developing and implementing intelligent resource management plans.

It is believed that the greatest limitations to the realization of full benefit from satellite imagery will be (1) the orderly collection

of adequate ground truth information, (2) the training of personnel to interpret and use the imagery and (3) the development of techniques for rapid interpretation of this imagery. Thus, greater effort will be required to investigate range conditions and management problems in varied regions of the world and ~~(2)~~ to prepare the necessary training aids which will be indispensible for teaching personnel to interpret the information which is anticipated from space imagery.

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APPENDIX I: Remote Sensing of Range Environments Conducted by Other Researchers

Remote sensing applied to studies of range environments is a newly developing field which promises to provide significant improvements over presently accepted techniques for accomplishing this task. In order that the reader may become familiar with the various kinds of remote sensing research in range environments conducted in this country, the following brief description is given:

Dr. Charles E. Poulton, Professor of Range Ecology, Oregon State University, is using conventional panchromatic minus-blue aerial photography (scales 1/20,000; 1/15,840; and 1/12,000) to determine the characteristics of various kinds of land in isolated school-land sections throughout the state of Oregon. A maximum of 20% of the total land area will be examined and photo interpretation keys and mapping legends will be prepared. This research is sponsored by the Oregon State Land Board.

In addition, Dr. Poulton is interpreting conventional panchromatic photography of lands administered by the Bureau of Land Management in order to develop guides, aids and keys to aerial photo interpretation of land surface and vegetation features as an aid in the refinement and reduction of cost of ecological resource analyses. Furthermore, Dr. Poulton is analyzing line-scan imagery, obtained by the University of Michigan's optical mechanical scanner, and multispectral photography in an effort to identify and characterize selected shrub-steppe ecosystems. He is also interested in interpreting and mapping native vegetation and related resources from color photography taken at earth orbital altitudes.

Dr. Richard Driscoll, of the Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colorado, project FS-RM-1707 and Dr. Olof C. Walmo, FS-RM-1801, are studying the applications of large scale, color and color infrared photography for evaluating livestock and wildlife habitat. The test locations of their study include a mountain bunchgrass range in the Black Mesa area on the Gunnison National Forest, Colorado, and a mixed sagebrush game range near Kremmling, Colorado. This research is a cooperative effort between the Remote Sensing Laboratory at the University of California, the Forestry Remote Sensing Project at the Pacific Southwest Forest and Range Experiment Station (FS-PSW-2204, Robert C. Heller, Project leader) and the Range Inventory and Evaluation Project, FS-RM-1707.

Dr. Paul Tueller, of the Renewable Resources Center, University of Nevada, is studying color stereo photographs taken on the ground, and large scale aerial color photography of twelve range watersheds near Reno, Nevada. Dr. Tueller is examining the problem of detecting vegetation differences in time and in space which may be used for evaluation of range condition and classification. His research effort is sponsored by the Bureau of Land Management.

Jack N. Reppert, of the Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colorado, and David M. Carneggie, of the Remote Sensing Laboratory, University of California, Berkeley, are cooperating on a research study at the Harvey Valley Range Allotment (NASA Test Site No. 135) on the Lassen National Forest which seeks to determine the usefulness of large scale (1/600 to 1/1,000) color and Color Infrared stereo photography for evaluating range conditions and analyzing range trend.

Marvin Heilman, Agriculture Research Service, USDA, Weslaco, Texas, is studying soil surface characteristics using multispectral photography and line scan imagery in an effort to evaluate site productivity of shrub (mesquite)-grass range near Rio Grande, Texas.

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